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Control Options For Lead Phase-down In Motor Gasoline

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Economic and Technical Review
Report EPS 3-AP-83-1

Air Pollution Control Directorate
February 1983

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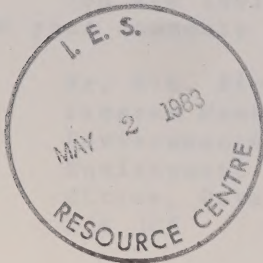


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Ottawa, Ontario
K1A 1C8

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MAR 14 1983

Dear Sir or Madam:

Amendment of Leaded Gasoline Regulations

The Minister of the Environment has concluded, on the basis of advice received from the Department of National Health and Welfare, that the existing Clean Air Act regulation limiting the lead content of leaded gasoline to 0.77 grams per litre (3.5 grams per Imperial Gallon) is inadequate and that a phase-down of lead in gasoline is necessary.

As announced on March 12, 1983 in the Canada Gazette, Part I, Environment Canada is seeking advice on the pace and extent at which this phase-down should occur. An information package, a copy of which is attached, has been prepared to assist interested parties in providing this advice. The package consists of the following studies:

- Environmental Protection Service, Control Options for Lead Phase-Down in Motor Gasoline;
- Environmental Protection Service, Summaries of Engineering Consultant Studies Related to Lead Phase-Down in Gasoline; and,
- Department of National Health and Welfare, Human Exposure to Environmental Lead.

Also, the individual consultant studies are available for review at Environment Canada Headquarters, Regional and District Offices. A list of these locations is included in the Summaries document.

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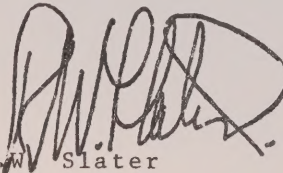
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You are invited to examine these documents and to provide your comments and reactions, prior to May 11, 1983, to:

Mr. M.E. Rivers, Director
Program Management Branch
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

After consideration of public response, the Minister will propose an appropriate amendment to the Leaded Gasoline Regulations.

Yours sincerely,

A handwritten signature in dark ink, appearing to be 'R.W. Slater', written over a horizontal line.

R.W. Slater
Assistant Deputy Minister

Attch.



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CONTROL OPTIONS FOR LEAD PHASE-DOWN IN MOTOR GASOLINE

J. Labuda and F. Landheer
Fuel Processes Division
Air Pollution Control Directorate
Environment Canada

ENVIRONMENTAL PROTECTION SERVICE REPORT SERIES

Economic and Technical Review Reports relate to state-of-the-art reviews, library surveys, industrial inventories, and their associated recommendations where no experimental work is involved. These reports are undertaken either by an outside agency or by the staff of the Environmental Protection Service.

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Inquiries pertaining to Environmental Protection Service Reports should be directed to the Environmental Protection Service, Environment Canada, Ottawa, Ontario, Canada, K1A 1C8.

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PREFACE

In July, 1974, Environment Canada promulgated Leaded Gasoline Regulations (P.C. 1974-1708), under which the maximum concentration of lead in gasoline is not to exceed 0.77 grams per litre (3.5 grams per imperial gallon). Subsequently, in October 1980 the Minister of the Environment, pursuant to provisions of the Clean Air Act, announced an investigation into the merits of developing regulations to reduce the allowable lead content of motor gasoline.

This investigation was designed to assess the lead emission reductions and costs associated with various control options. To assist in this assessment, independent consultants were commissioned to prepare technical feasibility/cost studies of the impact of reducing, or eliminating, the use of lead additives in gasoline.

As a result of this investigation, the following reports are available:

- 1) Control Options for Lead Phase-down in Motor Gasoline;
- 2) Summaries of Engineering Consultant Studies Related to Lead Phase-Down in Gasoline.

In a complementary study, Health and Welfare Canada has assessed the impact on the health of the public of lead emissions to the environment. Their report, "Human Exposure to Environmental Lead" is also available.

All those concerned are invited to examine these documents and provide comments, within the next 60 days, to:

Mr. M.E. Rivers
Director
Program Management Branch
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

These comments will be considered during the development of amended Leaded Gasoline Regulations.

PRÉFACE

En juillet 1974, Environnement Canada faisait promulguer le Règlement sur l'essence au plomb (C.P. 1974-1708) en vertu duquel la teneur en plomb dans l'essence ne devait pas dépasser 0,77 gramme par litre (3,5 grammes par gallon impérial). En octobre 1980, en vertu de la Loi sur la lutte contre la pollution atmosphérique, le ministre de l'Environnement annonçait la tenue d'une étude sur le bien-fondé d'un règlement visant à réduire la teneur permise en plomb des essences à moteur.

Cette étude devait servir à estimer les réductions des émissions de plomb selon les diverses options possibles ainsi que les coûts de ces dernières. À cette fin, des consultants indépendants ont été chargés de préparer des études de faisabilité technique et des coûts de la réduction ou de l'abandon de l'usage des additifs au plomb dans l'essence.

Cette étude a abouti aux rapports suivants:

1. Options de contrôle pour la réduction des quantités de plomb dans l'essence à moteur.
2. Sommaires des études de génie-conseil sur la réduction des quantités de plomb dans l'essence.

Dans une étude complémentaire, Santé et Bien-être Canada a évalué les répercussions sur la santé des émissions de plomb dans l'environnement. Cette étude intitulée: L'exposition humaine au plomb présent dans le milieu, peut aussi être consultée.

Toutes les personnes intéressées sont invitées à prendre connaissance de ces documents et à faire parvenir leurs observations d'ici 60 jours à:

M. M.E. Rivers
Directeur
Gestion des programmes
Service de la protection de l'environnement
Environnement Canada
Ottawa, Ontario
K1A 1C8

Il sera tenu compte de ces observations en vue de la modification du Règlement sur l'essence au plomb.

TABLE OF CONTENTS

	Page
PREFACE	i
PRÉFACE	ii
LIST OF TABLES	v
LIST OF FIGURES	vii
SUMMARY	viii
CONVERSION FACTORS	xi
1 GENERAL OVERVIEW	1
1.1 Global	1
1.2 Total Atmospheric Lead Emissions in Canada	3
2 PATHWAY ANALYSIS OF LEAD IN THE ENVIRONMENT	8
2.1 Lead Sources	8
✓ 2.1.1 Atmospheric Contributors	8
2.1.2 Aquatic System	8
2.1.3 Miscellaneous Sources	9
2.1.4 Food	9
2.2 Lead Intake by Canadians	12
✓ 2.3 Ambient Lead Levels	13
✓ 2.4 Gasoline Lead Loadings in Cities	17
✓ 2.5 Regulations on Lead in Gasoline	20
3 REGULATION IMPACT ON INDUSTRY	23
✓ 3.1 Automotive Manufacturing	23
✓ 3.1.1 Compression Ratio and Gasoline Octane Requirement	23
✓ 3.1.2 Automotive Exhaust Emissions	24
✓ 3.1.3 Need for Leaded Gasoline	25
3.2 Petroleum Refining Industry	26
✓ 3.2.1 Historical Gasoline Demand	26
✓ 3.2.2 Historical Leaded and Lead-Free Gasoline Demand	29
✓ 3.2.3 Future Gasoline Demand	30
✓ 3.2.4 Lead Usage by Refiners	34
✓ 3.2.5 Refinery Facilities	34
✓ 3.2.6 Other Studies	38
✓ 3.2.7 Refinery Energy Penalty	40
✓ 3.2.8 Alternatives	41
3.3 Fuel Additive Manufacturing Industry	43
3.4 Automotive Parts and Service Industry	44
3.5 Primary Lead Industry	45

	Page
4 AUTOMOTIVE LEAD EMISSION CONTROL	46
4.1 Control Options	46
4.2 Assessment and Conclusions	47
4.2.1 Automotive Lead Emissions	47
4.2.2 Capital and Operating Costs	48
4.2.3 Refinery Operating Costs	53
4.2.4 Lead Trap Costs	53
4.2.5 Benefits	54
4.2.6 Incremental Costs and Benefits	55
4.2.7 Benefit/Cost Ratio	56
4.2.8 Conclusions	56
REFERENCES	57
APPENDIX I	63
APPENDIX II	67

LIST OF TABLES

Table	Page
1 LEAD REDUCTIONS, AND COSTS/BENEFITS FOR CONTROL OPTIONS, FROM 1982 TO 2000	x
2 LEAD CONCENTRATIONS IN NORTH AMERICA	2
3 GLOBAL LEAD EMISSIONS FROM NATURAL AND MAN-MADE SOURCES	3
4 ATMOSPHERIC LEAD EMISSIONS IN CANADA IN 1970 AND 1978	4
5 1970 LEAD EMISSIONS IN CANADA, (UPDATE NO. 2)	5
6 LEAD EMISSIONS IN CANADA, 1972	6
7 RANGE OF LEAD CONTENT IN FOODS, CANADA	12
8 ANNUAL LEAD INTAKE BY CANADIANS	13
9 PARTICULATE LEAD, ANNUAL GEOMETRIC MEANS FOR SELECTED NAPS STATIONS ($\mu\text{g}/\text{m}^3$)	16
10 CURBSIDE LEAD LEVELS MEASURED DURING A SPECIAL STUDY IN 1972	17
11 ESTIMATES OF LEAD EMISSIONS, FROM 1977 GASOLINE SALES DATA, FOR SELECTED CITIES	18
12 CORE AREAS AND ESTIMATED GASOLINE LEAD DEPOSITION, FOR SELECTED CITIES	19
13 POPULATION DENSITY IN SOME CANADIAN AND AMERICAN CITIES	19
14 MAXIMUM ALLOWABLE LEAD CONTENT IN LEADED GASOLINE	21
15 LEAD CONTENT IN TOTAL GASOLINE PRODUCTION, 1981	21
16 ALL NEW AUTOMOBILES RESTRICTED TO LEAD-FREE GASOLINE	21
17 LEAD ADDITIONS TO GASOLINE BY VARIOUS COUNTRIES, 1977	22
18 REFINERY CAPACITY IN CANADA, 1979	27
19 CANADIAN GASOLINE PRODUCTION, 1930 TO 1980	29
20 GASOLINE PRODUCTION IN CANADA, 1975 TO 1981	29
21 LEAD ADDED TO CANADIAN GASOLINE	30
22 LEAD CONTENT OF GASOLINES IN CANADA	30
23 FUTURE FUEL DEMAND IN CANADA	32
24 REFINERY GASOLINE PRODUCTION COMPONENTS, 1979	36
25 MOTOR GASOLINE OCTANE NUMBER AND PRODUCTION, 1979	36

Table	Page
26 CANADIAN GENERAL STANDARDS BOARD OCTANE NUMBER SPECIFICATIONS FOR GASOLINE	36
27 CAPITAL AND DIRECT OPERATING COSTS FOR GASOLINE CONTAINING 1.3 AND 0.68 GRAMS OF LEAD PER GALLON	38
28 ESTIMATES OF REFINERY CAPITAL COSTS FOR 94 RON GASOLINE	39
29 REFINERY ENERGY PENALTY, INCREMENTAL CRUDE OIL REQUIREMENTS	41
30 CUMULATIVE LEAD EMISSIONS, 1986 TO 2000, FOR VARIOUS CONTROL OPTIONS	47
31 ESTIMATED REFINERY CAPITAL INVESTMENT COSTS FOR CONTROL OPTIONS 2, 3, 4 AND 5	48
32 ESTIMATED REFINERY ANNUAL OPERATING COSTS FOR CONTROL OPTIONS 2, 3, 4 AND 5	53
33 ESTIMATED ANNUAL DIFFERENTIAL COST FOR LEAD TRAPS	54
34 OPERATING COST SAVINGS FOR OPTIONS 4 AND 5	55
35 LEAD EMISSION REDUCTIONS, COSTS AND BENEFITS FOR CONTROL OPTIONS	55
36 SUMMARY OF CONTROL OPTIONS FOR LEAD PHASE-DOWN IN GASOLINE	68
37 VEHICLE POPULATION AND FLEET RATING	69
38 ESTIMATED GASOLINE PRODUCTION AND DEMAND, 1986 TO 2000	70
39 ESTIMATED AUTOMOTIVE LEAD EMISSIONS, 1986 TO 2000	71
40 ESTIMATED COSTS FOR CONTROL OPTIONS	72
41 INCREMENTAL SAVINGS FOR LEAD-FREE GASOLINE OPTION	73

LIST OF FIGURES

Figure		Page
1	ATMOSPHERIC LEAD EMISSIONS BY REGIONS, 1972	7
2	THE SOIL- AND AEROSOL-DERIVED Pb IN LETTUCE (L) AND OAT (O) TOPS GROWN IN FOUR SOILS OF DIFFERENT Pb CONTENT IN MOUNTAINS AND ALONG A FREEWAY CARRYING 360 000 CARS/DAY	11
3	PARTIAL PATHWAYS FOR LEAD IN THE CANADIAN ENVIRONMENT FOR 1972	14
4	SIMPLIFIED REFINERY FLOW DIAGRAM	28
5	GASOLINE PRODUCTION IN CANADA	31
6	CANADIAN GASOLINE USAGE BY VEHICLE CLASS, 1975-2000	33
7	AUTOMOTIVE LEAD EMISSIONS IN CANADA	35
8	RESOURCE LIFE VERSUS REFINERY ENERGY PENALTY	42
9	FORECAST OF AUTOMOTIVE LEAD EMISSIONS FOR VARIOUS OPTIONS	49
10	FORECAST OF AUTOMOTIVE LEAD EMISSIONS WITH VARIOUS ALLOWABLE LEAD CONTENTS IN GASOLINE	50
11	FORECAST OF AUTOMOTIVE LEAD EMISSIONS WITH LEADED GASOLINE (0.68 g/gal) ALLOWED FOR HEAVY TRUCKS	51
12	FORECAST OF AUTOMOTIVE LEAD EMISSIONS FOR STATUS QUO AND FOR LEAD TRAP INSTALLATIONS	52
13	REFINERY MODEL OF BLOCK FLOW DIAGRAM	65
14	REFINERY SIMULATION FLOW DIAGRAM	66

SUMMARY

The emission of lead into the environment from natural and man-made sources eventually contributes to the lead inventory in the human body. Lead is not known to have any biological effects in man which can be considered beneficial; most effects appear to be adverse even with trace quantities of lead in the body.

Acute human health effects include convulsions, coma and death; however, industrial hygiene advances have virtually eliminated acute lead poisoning. Continual exposure to low lead levels in the environment is known to produce difficult-to-diagnose symptoms, such as fatigue, headache, poor appetite, clumsiness and diminished mental capability. Now, medical research also indicates that low level exposure can affect children and pregnant women. Deficiencies in psychology and classroom performance, with an effect on intelligence quotient, are being recorded for children.

Canada has taken some lead control measures to protect human health, such as reducing the lead content in paints, controlling emissions from secondary lead smelters and eliminating lead from kettles and baby food containers. Currently, the largest lead releases to the Canadian environment are from vehicles using leaded gasoline. For this lead emission source, Japan, the United States, the U.S.S.R., Australia and the European Economic Community have eliminated or reduced the use of lead in gasoline to protect human health. The United States has had a program in place since 1974 to reduce automotive lead emissions in 1990 by 80% of the 1974 value. However, on November 1, 1982, more stringent regulations were promulgated by the U.S. Environmental Protection Agency, which limit the lead content of leaded gasoline to an equivalent of 1.3 grams per (imperial) gallon. Under these new regulations, automotive lead emissions in 1990 should be reduced by 91% of the 1974 value. Environment Canada promulgated a regulation in 1974 which restricts the maximum lead content of gasoline to 3.5 grams per gallon; today this is one of the most lenient standards in industrialized nations.

In Canada, approximately 73% of man-made lead emissions to the atmosphere in 1972 were from automobiles using leaded gasoline. From the latest national emission inventory (1978) automotive lead emissions had decreased from the 1972 value of 12 800 tonnes to about 9 200 tonnes but these emissions were still 63% of the total lead emissions in Canada. Since 1975, most manufacturers have equipped automobiles with catalytic converters in order to meet automobile emission standards for hydrocarbons and carbon monoxide. The catalytic converter can only operate effectively with lead-free gasoline because lead damages the catalyst. Consequently, the introduction of catalyst-

equipped automobiles has reduced the demand for leaded gasoline during the last seven years and has reduced automotive lead emissions from 12 000 tonnes in 1975 to 8 000 tonnes in 1981. Current projections indicate that, if there are no changes in the lead content of gasoline regulations, these emissions should gradually decrease and stabilize at an annual rate of 6 000 tonnes by 2000.

For this study, control options were considered that would reduce future automotive lead emissions by a mechanical device (lead trap) or by various reductions in the lead content of gasoline. The lead-trap control-option is the least desirable because it would decrease lead emissions gradually (full implementation of this option would take 13 years) and because it could affect the development of emission standards for medium and heavy-duty vehicles which are currently uncontrolled. The lead-trap collects large lead particles but small particles are emitted and these are of respirable size and thus can have an impact on human health. Also, an expensive and complicated program would be required to enforce the use and disposal of lead-traps.

Reducing the lead content of gasoline will decrease the gasoline octane number and a minimum value for this fuel characteristic is essential to prevent early ignition or knock in the combustion chamber of the automotive engine. Gasoline octane number can be increased by adding high octane hydrocarbons produced by the petroleum refiner. If Canadian petroleum refiners were to construct octane improvement facilities and to produce only lead-free gasoline in 1986, it is estimated that the capital cost of these facilities would be \$43 million and the associated annual refinery operating costs would be \$32 million.

Using lead-free gasoline in automotive vehicles eliminates lead emissions and reduces maintenance requirements, which include spark plug changes and exhaust system replacements. It is estimated that such maintenance benefits should more than offset the additional cost of lead-free gasoline to the vehicle operator.

Emission, cost, and benefit estimates were developed for the control options and compared with the status quo; the results are summarized in Table 1.

As can be seen from the table, the least cost-effective option is the lead-trap. The most cost-effective options are the lead-free gasoline Options 4 and 5 and these options are comparable from the environmental and consumer viewpoints.

TABLE 1 LEAD REDUCTIONS, AND COSTS/BENEFITS FOR CONTROL OPTIONS, FROM 1982 TO 2000

Option	Allowable Lead Content in Leaded Gasoline (grams per gallon)	Lead Emission Reduction (tonnes)	Present Value (1982)				Benefit or (Cost)	
			Costs (\$ million)	Benefits (\$ million)	Net Benefit or (Cost) (\$ million)	Cost-Effectiveness Per Tonne Lead Benefit (Cost)	Benefit or (Cost)	
							(cents per gallon)	(cents per litre)
1	3.5 (status quo)	0	-	-	-	-	-	-
2	1.3	62 000	108	-	(108)	(1 740)	(0.6)	(0.13)
3	0.68	79 000	172	-	(172)	(2 180)	(0.9)	(0.20)
4	0	98 000	249	595	346	3 530	3.7	0.81
5	0 (except 0.68 for heavy truck gasoline)	92 000	249	505	256	2 780	2.9	0.64
6	3.5 (with lead-trap)	38 000	110	-	(110)	(2 890)	(0.8)	(0.18)

CONVERSION FACTORS

Both the metric and the English systems of units are used in this report; some factors for conversion between the two systems are:

1 cubic metre (m ³)	=	35.3 cubic feet
	=	0.16 barrels (oil)
1 tonne (1 000 kg)	=	1.1 short tons
1 kilogram (kg)	=	2.2 pounds
1 litre (L)	=	0.22 gallons
1 square kilometre (km ²)	=	0.386 square miles
1 gram/litre (g/L)	=	4.5 gram/gallon

It should also be noted that in this report gallons are in imperial units and not in U.S. liquid measure.

1 GENERAL OVERVIEW

The following information is presented in an effort to place the issue of lead in gasoline in perspective. It is a complex issue, with multiple interrelationships.

1.1 Global

Lead is one of the more commonly used metals in our industrial society with world production currently about 3 000 000 tonnes per year (1). The historic increase in the worldwide use of lead is reflected in the dramatic rise in the lead content of snow in Greenland, which also demonstrates the ubiquity of lead in modern society (2). Dated snow samples show that in 800 BC the lead content of snow was less than 0.0001 micrograms per kilogram ($\mu\text{g/kg}$). The lead content rose to 0.04 $\mu\text{g/kg}$ during the industrial revolution and increased to 0.08 $\mu\text{g/kg}$ with the introduction of the lead alkyl motor gasoline additive in the early years of the 20th century. By 1950 the lead content of snow had increased to 0.24 $\mu\text{g/kg}$.

Industrial lead contamination of the environment appears to be a worldwide phenomenon and results primarily from atmospheric transport of lead aerosols from smelters, automobile exhausts and reentrained dusts and smokes (3). Concentrations of lead in the air in the "cleanest" regions of North America are about 0.01 micrograms per cubic metre ($\mu\text{g/m}^3$). Even these relatively low concentrations are at least 100 times higher than the ambient concentrations which existed some 10 000 years ago (4). Estimates of past and present lead concentrations in the environment (4) are given in Table 2.

TABLE 2 LEAD CONCENTRATIONS IN NORTH AMERICA

Source	Natural Prehistoric	Contemporary		Maximum Permissible Levels**
		Remote	Urban*	
Air (ng* Pb/m ³)	0.04	8 to 10	1 000 to 20 000	1 500
Fresh Water (ng Pb/g)	<0.02	0.005 to 0.05	<1 to >50	50
Trees (ng Pb/g)	4	40	200	none
Human Food (ng Pb/g)	<2	200	200	300

* ng (nanogram) is gram x 10⁻⁹

** U.S. Department of Health, Education, and Welfare. Lead-based paint poisoning prevention in federal and federally assisted construction. 42 CFR 90, 37 Federal Register 4915, March 7, 1972.

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An inventory of the major sources of industrial and natural lead aerosols to the atmosphere (1,5) is given in Table 3.

TABLE 3 GLOBAL LEAD EMISSIONS FROM NATURAL AND MAN-MADE SOURCES

	Total Production	Emission Factor	Lead Emissions	
	(10 ⁶ kg/yr)	(g/kg)	(10 ⁶ kg/yr)	(%)
<u>Natural</u>				
Wind-blown and volcanic dust, sea spray, forest foliage, volcanic sulphur				
SUB-TOTAL	1 300 000	0.0015	2	-
<u>Man-Made</u>				
Lead alkyls	400	700.0	280	68
Iron smelting	780 000	0.06	47	12
Lead smelting	4 000	6.0	24	5
Zinc and copper smelting	15 000	2.8	42	10
Coal burning	3 300 000	0.045	15	5
SUB-TOTAL	4 100 000		408	
TOTAL	5 400 000		410	100

1.2 Total Atmospheric Lead Emissions in Canada

Since 1970, the relative importance of the various sectors contributing lead emissions to the atmosphere and the magnitude of their respective emissions have not changed appreciably (Table 4). The 1970 data, which are given in more detail in Table 5, are from an Environment Canada National Emission Inventory (6), and the 1978 data are preliminary estimates by Environment Canada.

TABLE 4 ATMOSPHERIC LEAD EMISSIONS IN CANADA IN 1970 AND 1978

Year of Survey	1970		1978	
Source	Short Tons	%	Short Tons	%
Gasoline Lead Additives	14 100	73	10 100	63
Lead-Containing Products	200	0.5	400	2
Inadvertent Sources*	3 400	18	4 100	26
Production of Lead	1 500	8	1 300	8
Miscellaneous	100	0.5	200	1
TOTAL	19 300	100	16 100	100

* Mostly from copper, nickel and iron production

The predominance of lead emissions from the use of leaded gasoline is typical for most countries. Automotive lead emissions accounted for 73% and 63% of the total Canadian atmospheric emissions in 1970 and 1978 respectively, even though there are large lead mining operations in Canada.

In 1976, Leah (7) published an environmental inventory study in which lead emissions in Canada in 1972 were estimated to be 18 700 tons (Table 6). He also estimated atmospheric lead emissions for various geographical regions in order to assess the impact of lead on watersheds in Canada, as shown in Figure 1. From these data, it was concluded that about 75% of the atmospheric lead emissions occur in Regions 1, 3, 5 and 6, which contain about 93% of the Canadian population.

TABLE 5 1970 LEAD EMISSIONS IN CANADA, (UPDATE NO. 2)*

Source	Emissions		Source	Emissions	
	Tons	Percent		Tons	Percent
CONSUMPTION			Ferroalloys		
Gasoline			Ferrosilicon	43.1	
Automobile	14 083.0	72.8	Others	28.6	0.4
Aviation	151.9	0.8	Iron foundries	23.3	0.1
Handling	9.2	*	Cement manufacture		
Solder			Wet process		
Soldering	0.7	*	Dry process	<u>111.5</u>	<u>0.6</u>
Joint buffing	3.8	*	Inadvertent Total	3 425.7	17.7
Printing industry	27.3	0.2			
Insecticide application	6.0	*	PRODUCTION		
Paint	<u>0.04</u>	<u>*</u>	Lead mining		2.1
Consumption Total	14 281.9	73.8	Underground	206.0	
			Open pit	195.0	
INADVERTENT SOURCES			Lead milling	565.0	2.9
Coal combustion			Lead smelting		2.4
Power plants	9.4		Blast furnace	141.0	
Coke production	0.13	0.1	Imperial furnace	316.8	
Other	3.76		Lead refining		0.3
Oil combustion	105.4	0.5	Betts process	19.3	
Wood combustion	46.4	0.2	Softening, desilvering	43.2	
Sewage sludge incineration	2.17	*	Secondary lead		0.2
Refuse incineration	58.3	0.3	Blast furnace	20.5	
Waste oil incineration	134.0	0.7	Reverberatory furnace	14.7	
Zinc production	37.3	0.2	Melting kettles	<u>5.3</u>	
Copper, nickel production	2 437.0	12.6	Production Total	1 526.8	7.9
Iron production			MANUFACTURING		
Sintering	95.1		Storage batteries		
Blast furnace	6.5	0.6	Oxide made	2.0	
Electric furnace	6.1		Oxide bought	1.4	*
Steel production			Gasoline additives	64.5	0.3
Basic oxygen furnace	32.1		Litharge	0.6	*
Open hearth furnace	210.6	1.4	Other compounds	0.01	*
Electric furnace	35.9		Metal fabrication	<u>38.0</u>	<u>0.2</u>
			Manufacturing Total	<u>106.5</u>	<u>0.6</u>
			TOTAL LEAD EMISSIONS	19 339.9	100.0

*Revised version of Reference No. 6

*Negligible (0.1%)

TABLE 6 LEAD EMISSIONS IN CANADA, 1972 (Tons)

Region	Releases from Production Activities	Releases from Selected Manufacturing Activities	Releases from Consumption of Leaded Gasolines*	Releases from Miscellaneous Sources**	Total Lead Emissions
1	390	7	1 230		1 627
2	530	-	60		590
3	10	8	2 150		2 168
4	20	-	160		180
5	65	157	7 930		8 152
6	950	3	1 070		2 023
7	-	-	660		660
				3 300	3 300
TOTAL	1965	175	13 260	3 300	18 700

* This emission is based on the assumption that 75% of the lead in gasoline is emitted from the automobile.

** Miscellaneous sources include:

- the residuals from production of other metals and alloys;
- cement manufacturing;
- the combustion of coal, oil and wood;
- the incineration of refuse and sewage sludge.

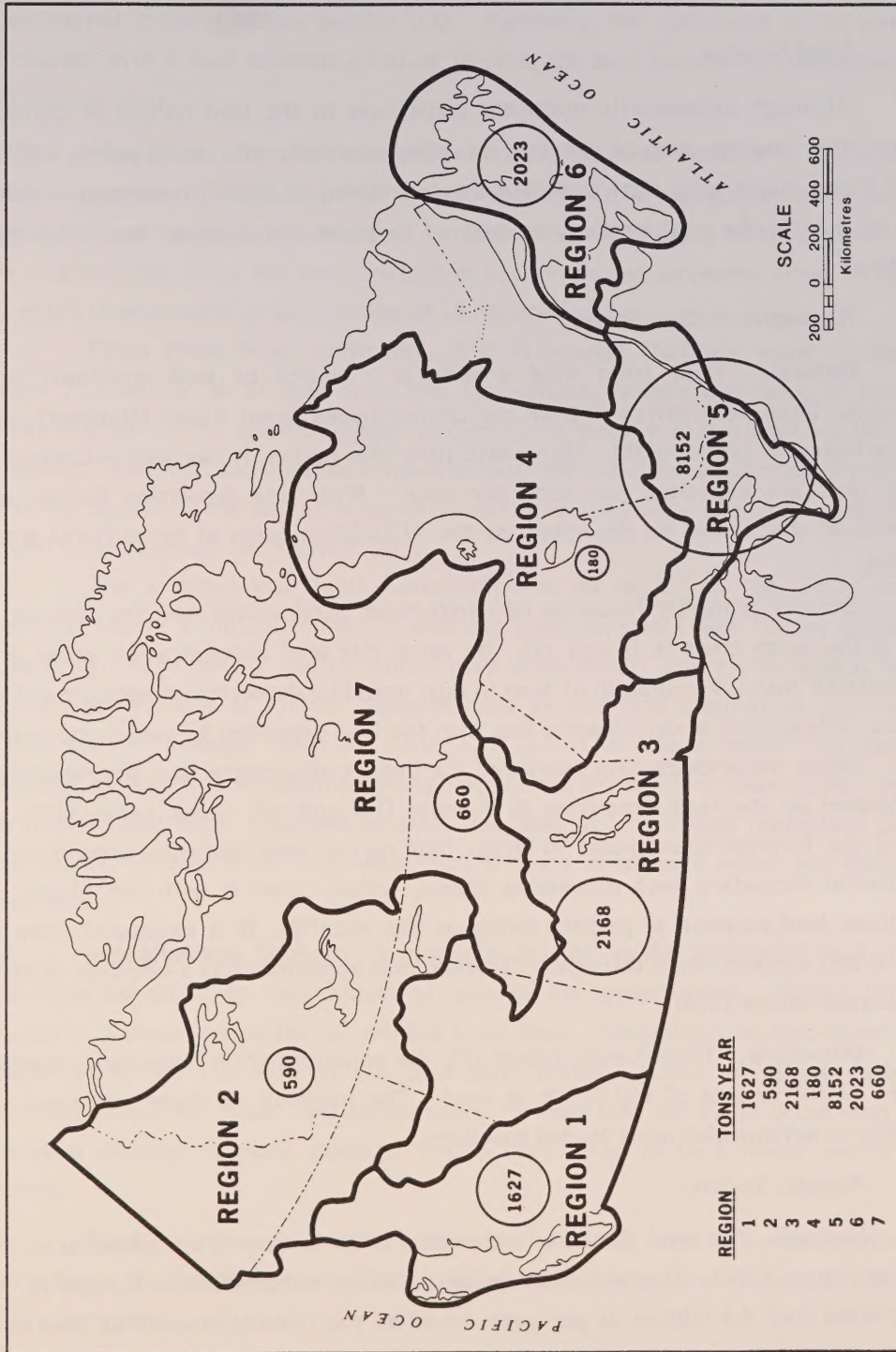


FIGURE 1 ATMOSPHERIC LEAD EMISSIONS BY REGIONS, 1972

2 PATHWAY ANALYSIS OF LEAD IN THE ENVIRONMENT

2.1 Lead Sources

Although atmospheric emissions contribute to the lead burden of Canadians, there are other sources such as the lead in drinking water, soil, dust, paints and food. Some of these major lead contributors were considered in order to develop a pathway analysis of lead in the environment, as well as to place atmospheric lead emissions in perspective.

2.1.1 Atmospheric Contributors

2.1.1.1 Natural. Dust from wind erosion is a source of lead emissions to the environment. Data were reviewed from the United States Great Plains (Midwest) region, which is a high dust producer (8). Using data from this region, it has been estimated that 500 lb of dust are deposited per acre per year. With this deposition factor, about 55 billion lb of dust would be deposited on the 110 million acres of agricultural lands in Canada (9).

Dust is primarily made up of earth crust particulates and the average lead content in the earth crust is 16 ppm (6). By using this lead concentration value, it has been calculated that 0.9 million lb of lead in dust would be deposited on agricultural lands in Canada. This deposit is significantly less than the lead deposited by man-made sources.

Other researchers have measured the impact of airborne lead and reports have been published on the lead deposition in Toronto (10) and the Great Lakes (11). The authors of the Toronto report point to higher than normal lead concentrations in soil and foliage around secondary lead processing plants, which coincide with the higher than normal blood lead content of persons living in the vicinity. It is estimated from lead analyses of soil samples taken throughout Toronto that approximately 10 million lb of lead were deposited before 1974.

2.1.1.2 Man-Made. From Leah's report (7), the emissions from man-made sources in 1972 were 18 700 tons or 37 400 000 lb of lead. The majority of these emissions were attributable to automobiles using leaded gasoline.

2.1.2 Aquatic System

2.1.2.1 Natural. The total Canadian water flow to the oceans is estimated to be 3 600 billion tons per year (12). Assuming that uncontaminated water contains 0.5 ppb of lead, it is estimated that 3.6 million lb per year would be the natural amount of lead in the

the water flow to the oceans. The eroded sediments which are carried in the water flow are estimated to be 1 billion tons/yr (13). Assuming the sediments to be earth crust particulates with a lead concentration of 16 ppm, the lead associated in sediments would be 32 million lb/yr.

2.1.2.2 Man-Made. Because of contamination, the lead content of uncontaminated water has increased from 0.5 ppb to about 3 ppb (14). This 2.5 ppb increase in the lead concentration of water is equivalent to 18 million lb of lead being added to water by man-made sources. Similarly the lead content in sediments has increased from 16 to 25 ppm (14), which is equivalent to an increase of 18 million lb/yr.

From these broad estimates, it is concluded that the water system would transfer 71.6 million lb of lead from the atmosphere, waters and lands to the oceans. Natural and man-made sources appear to contribute equally to the lead burden reaching the oceans. However, some authors indicate that more lead has been transferred from the land to the oceans by the use of tetraethyl lead as an antiknock additive in gasolines than has been added through the rivers (15).

The International Joint Commission in its report on the Great Lakes (11) stated that nearly 8 million tonnes of lead per year entered Lakes Huron, Ontario, Erie and Superior. More than 3 million tonnes were deposited by direct atmospheric transport. The transport feature is further demonstrated by the lead content of rain which, in Toronto, has an average value of 50 $\mu\text{g/L}$ (11). It is also stressed (11) that a high percentage of lead in lake sediments originates from atmospheric deposition. Sediments have traditionally been regarded as sinks for lead in which lead methyrate can form. Consequently, lead-enriched sediments may produce conditions which are hazardous to aquatic biota.

2.1.3 Miscellaneous Sources. In previous studies on the effects of lead on health, paints were identified as contributors of lead to the environment. During 1972, paint produced in Canada contained 6.7 million lb of lead. Application of lead-based paint to surfaces should fix the lead in the film upon drying. Lead emissions during paint application should be minor and entrainment of lead into air could occur only through mechanical abrasion or paint flaking. This is considered to be a minor source of lead emissions.

2.1.4 Food. Various studies have been made on the level of contaminants in food which indicate that the lead content of food may be due to uptake from soils, atmospheric deposits, or water.

Jaworski (14) quotes a 1974 study by Rabinowitz which considered the relative contribution of lead from soil and aerosols to the lead content of washed lettuce and oat tops grown in soils of different lead content in mountains and along a freeway (see Figure 2). The soil lead had a different isotopic composition from the aerosol lead and isotopic analysis permitted accurate determination of the relative lead contributions from the two sources. The lead accumulation by the plants depends upon the relative lead content in soils or aerosols. Man-made sources make a contribution to the lead content in food not only from aerosols but also from aerosol deposition which increases the lead content of soil and results in a root uptake from the soil.

The average lead intake from food and drink has been quoted to be as high as 274 $\mu\text{g}/\text{d}$ (16) and Health and Welfare Canada (17) gives the range of lead contents in foods (Table 7).

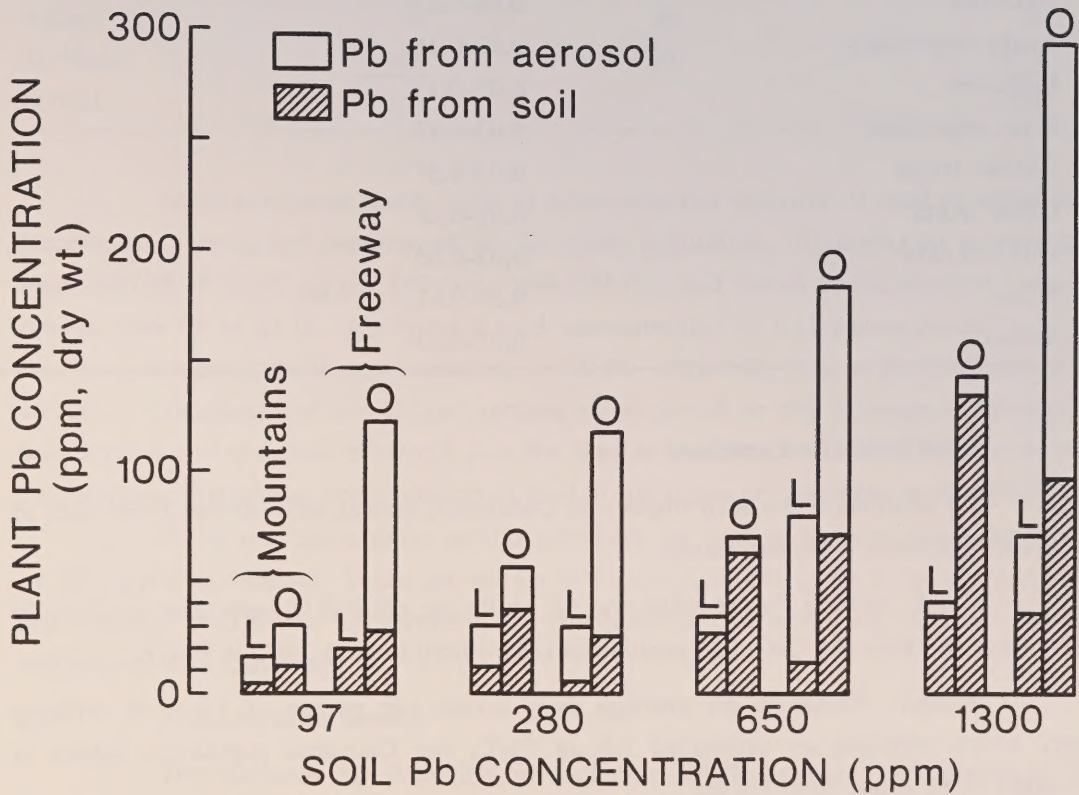


FIGURE 2

THE SOIL- AND AEROSOL-DERIVED Pb IN LETTUCE (L) AND OAT (O) TOPS GROWN IN FOUR SOILS OF DIFFERENT Pb CONTENT IN MOUNTAINS AND ALONG A FREEWAY CARRYING 360 000 CARS/DAY

TABLE 7 RANGE OF LEAD CONTENT IN FOODS, CANADA

Constituent of Diet	Range of Lead Concentration ($\mu\text{g/g}$)
1. Milk and dairy food	0.02-0.24
2. Meat, fish, poultry	0.05-0.26
3. Cereals	0.03-0.36
4. Potatoes	0.06-0.25
5. Leafy vegetables	0.03-0.18
6. Legumes	0.03-0.13
7. Root vegetables	0.03-0.17
8. Garden fruits	0.03-0.57
9. Other fruits	0.02-0.27
10. Oils and fats	0.02-0.05
11. Sugar	0.05-0.41
12. Drinks	0.01-0.05

2.2 Lead Intake by Canadians

To determine the lead impact on Canadians, annual lead intakes from each of the following sources were estimated.

Food. 113 μg Pb per adult and 62 μg Pb per child (17) were used as the daily food intake, and thus the Canadian population (23 million) ingests 2 070 lb Pb/yr.

Water. Assuming an average daily intake per person of 1.4 L of drinking water, which contains an estimated 1.0 μg Pb/L, the Canadian population intake is calculated to be about 30 lb Pb/yr.

Air/Dust. Health and Welfare Canada estimates that the daily intake of lead for the average adult and child is: air inhalation, 8 μg and 2.4 μg ; dust, 10 μg and 50 μg , respectively (17). Based on these averages, the lead intake of Canadians from air and dust is 450 lb/yr.

Using Health and Welfare's absorption factors, the absorption of lead by Canadians from these three sources is given in Table 8.

TABLE 8 ANNUAL LEAD INTAKE BY CANADIANS

Source of Lead	Canada (lb/yr)		Absorbed
	Intake	Absorption Percentage	
Food	2 070	13	270
Water	30	50	15
Air/Dust	450	25	115
TOTAL	2 550		400

Some estimates were made to determine the quantity of lead retained in the bloodstream, tissue and skeleton of the Canadian population. Assuming an average blood lead level of 18 to 25 μg per 100 millilitres (14) the lead stored in the blood of Canadians ranges from 47 to 65 lb. Assuming a lead concentration of 0.12 grams in the body (14), the lead in Canadians is approximately 6 100 lb. However, this is the cumulative lead stored in Canadians and the annual accumulation should be the difference between the body intake and the lead excreted plus the lead in the bloodstream. From the previous calculations, this annual accumulation of lead in the tissue and skeleton is about 400 lb/yr.

Using the above data, partial pathways for lead in the Canadian environment in 1972 were developed. These are shown in Figure 3, which gives a comparison of the quantities of lead in the environment and the quantities of lead being ingested, absorbed and excreted by Canadians.

2.3 Ambient Lead Levels

The National Air Pollution Surveillance (NAPS) network, established in 1969, monitors the ambient air in major population centres across Canada. By March 31, 1978, the network comprised 554 instruments (including 271 continuous gaseous pollutant monitors) located at 157 stations in 54 cities. Data from these stations are compiled by the Air Pollution Control Directorate of Environment Canada and monthly as well as annual summaries are published (18). The network measures the level of contaminants in ambient air and permits the detection of air pollution trends.

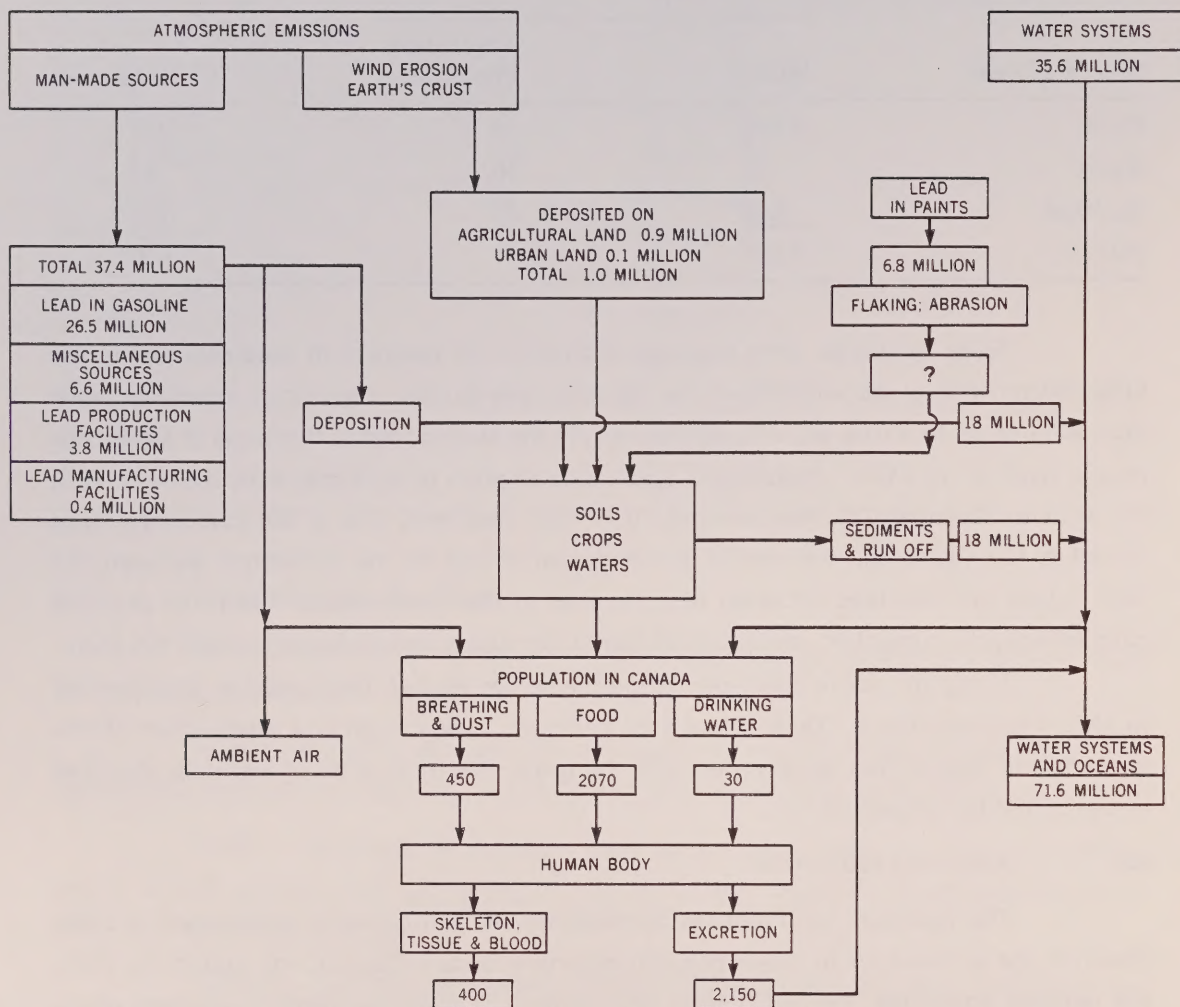


FIGURE 3

PARTIAL PATHWAYS FOR LEAD IN THE CANADIAN ENVIRONMENT FOR 1972

The lead concentration in ambient air is determined at about 90 NAPS sites across Canada. From these data, nine sites in six major cities were selected as being downtown sites or being near heavy traffic areas (Table 9). The annual geometric mean of lead content at these stations shows a downward trend from 1974 to 1978. However, one should use these data with caution for inter-station comparisons because the stations might be at different heights or distances from major roadways (19). It may also be noted that the ambient air lead levels decreased by 38 to 66% at various stations (20) in Eastern Canada but that lead consumption in gasoline decreased by only 26%.

In a special study conducted in Vancouver, Toronto and Montreal during 1972 (21), lead measurements were taken six feet above the curbsides of heavy traffic areas. The comparative measurements for NAPS and curbside stations are shown in Table 10. The curbside stations indicated the ambient lead levels to be from 3.3 to 13.7 $\mu\text{g}/\text{m}^3$ for 15 hours whereas the NAPS station ambient lead levels ranged from 0.6 to 1.9 $\mu\text{g}/\text{m}^3$ for the monthly arithmetic mean.

TABLE 9 PARTICULATE LEAD, ANNUAL GEOMETRIC MEANS FOR SELECTED NAPS STATIONS ($\mu\text{g}/\text{m}^3$)

	Montreal		Ottawa		Toronto		Hamilton		Vancouver		Victoria	
	50108	50109	60101	60101	60401	60403	60501	60501	00106	00108	00301	00301
Height Above Street Level	14 m	3 m	16 m	16 m	20 m	1 m	4 m	4 m	17 m	10 m	14 m	14 m
1974	1.03	3.78	1.17	1.17	1.22	1.72	1.1	1.1	0.97	0.97	0.76	0.76
1975	0.86	2.62	1.18	1.18	0.91	1.34	0.19	0.19	0.91	0.83	-	-
1976	0.88	2.26	0.81	0.81	-	-	0.7	0.7	-	0.91	0.56	0.56
1977	0.69	1.61	0.67	0.67	-	1.22	0.8	0.8	0.72	0.83	0.46	0.46
1978	0.55	1.35	0.53	0.53	0.66	0.99	-	-	0.60	0.75	0.36	0.36

NOTE: These stations were selected because they were downtown sites or near heavy traffic areas.

TABLE 10 CURBSIDE LEAD LEVELS MEASURED DURING A SPECIAL STUDY IN 1972

		15-hour average - $\mu\text{g}/\text{m}^3$		
		July Vancouver	July Toronto	March Montreal
Average lead levels at 6 curbside sites over a 5 to 6 day sampling period	Site 1	13.5	11.8	4.8
	Site 2	4.9	13.7	3.4
	Site 3	4.0	5.3	3.5
	Site 4	10.0	8.4	4.0
	Site 5	6.2	7.9	3.1
	Site 6	10.9	3.3	4.3
	Sampling Period	5 days consecutive	6 days non-consecutive	5 days consecutive
		Monthly arithmetic mean - $\mu\text{g}/\text{m}^3$		
Lead levels at existing NAPS stations during the month of special sampling	Downtown	1.1	1.4	1.5
	Other Stations	0.6	1.5	1.9
		0.6	1.3	1.3
		---	---	1.5
		---	---	1.9

The curbside stations show that ambient lead levels are significantly higher than the values recorded by the NAPS network and it would be perhaps more realistic if health effects were based on curbside lead levels rather than on average NAPS values.

2.4 Gasoline Lead Loadings in Cities

Leaded gasoline sales data for 1977 were used to calculate the automotive lead emissions for various cities in Canada and also for New York City. From Table 11 it may be noted that the highest gasoline lead emissions in Canada are in Montreal.

TABLE 11 ESTIMATES OF LEAD EMISSIONS, FROM 1977 GASOLINE SALES DATA, FOR SELECTED CITIES

	(million lb of lead)
Montreal	1.2
Toronto	0.8
Edmonton	0.94
Vancouver	0.65
Winnipeg	0.34
Regina	0.26
Quebec	0.19
Halifax	0.14
Sarnia	0.07
New York City	7.6

These gasoline lead emissions were divided by the areas of the city cores and the gasoline lead deposition in pounds of lead per square mile was determined for the various cities (Table 12). It may be observed that the annual gasoline lead deposition in Toronto and Montreal is comparable to that in New York City.

Statistics for population density in some Canadian and American cities are shown in Table 13. It may be observed that the Montreal and Toronto population densities are comparable to New York City. From these statistics, one concludes that the gasoline lead deposits and population densities are comparable for New York City, Montreal and Toronto. It is expected that the gasoline lead deposition will decrease annually in New York City but the same reduction cannot be anticipated in Toronto and Montreal because the Canadian gasoline lead phase-down program is currently not as stringent as the phase-down program in the United States.

TABLE 12 CORE AREAS AND ESTIMATED GASOLINE LEAD DEPOSITION FOR SELECTED CITIES

	Central City Core Area, 1971 (square miles)	Estimated Gasoline Lead Deposition, 1977 (lb per square mile)
Montreal	49	24 500
Toronto	33	24 200
Edmonton	108.5	8 700
Vancouver	44	14 800
Winnipeg	30.5	11 200
Regina	29.5	8 800
Quebec	27.6	7 000
Halifax	24.2	6 000
Sarnia	12.7	5 100
New York City	300	25 300

TABLE 13 POPULATION DENSITY IN SOME CANADIAN AND AMERICAN CITIES (1971 data)

	Population - Urbanized City (persons)	Population - Central City (persons)	Area - Central City (sq. miles)	Population Density - Central City (persons/sq. mile)
Montreal	2 437 000	1 145 000	49	23 500
Toronto	1 881 000	665 000	33	20 000
Edmonton		438 152	108.5	4 000
Vancouver	1 000 000	440 000	44	10 000
Winnipeg		246 246	30.5	8 100
Regina		139 469	29.5	4 700
Quebec		186 088	27.6	6 700
Halifax		122 035	24.2	5 100
Sarnia		57 644	12.7	4 500
New York City	16 200 000	7 894 900		26 300
Chicago	6 714 600	3 367 000		15 100
Pittsburgh	1 846 000	520 100		9 400
Dallas	1 338 700	844 400		3 200

2.5 Regulations on Lead in Gasoline

To protect human health, several countries have developed regulations which limit the lead content in motor gasoline. A complete list of regulations may be found in Reference 22. Some lead-in-gasoline and related standards are given in Tables 14 to 16.

The British government announced in 1981 that the lead concentration in gasoline was to be reduced to 0.15 g/L by 1986. Australian States adopted the recommendations of the Transport Advisory Council which stipulate that vehicles manufactured after January 1, 1986, would be designed to operate on unleaded petrol.

In April 1975, Japan set stringent automobile emission standards that could only be met by using catalytic converters and lead-free regular gasoline. In order to prevent valve seat recession and knock in older cars, leaded premium gasoline was also produced. Premium gasoline sales were 21% of the total gasoline production in May 1975 but these sales had declined to 8% by 1978.

In the United States, the Environmental Protection Agency (EPA) initiated a lead-in-gasoline phase-down program in 1974 with the intention of substantially reducing automotive lead emissions, that were expected to be 186 000 tonnes in 1974. The U.S. EPA predicted that these emissions should decline to 48 000 tonnes of lead in 1983 and 39 000 tonnes in 1990 or about 80% reduction of automotive lead emissions by 1990. The U.S. EPA subsequently promulgated a more stringent regulation (23) on November 1, 1982, which should reduce the 1974 emission level by 91% to 16 000 tonnes in 1990.

The May 1978 issue of the "World-Wide Survey of Motor Gasoline Quality" published by the Associated Octel Co. Ltd. in London, England, was used to determine the lead consumption in gasoline for various countries in 1977. These data are given, with the population for each country, in Table 17.

TABLE 14 MAXIMUM ALLOWABLE LEAD CONTENT IN LEADED GASOLINE

Country	(Grams Lead per Litre)	Effective Date
<u>Leaded Gasoline</u>		
New Zealand	0.84	1967
Greece	0.84	April, 1966
Canada	0.77	January, 1976
Sweden	0.15 (Regular)	January, 1980
	0.15 (Premium)	July, 1981
Switzerland	0.15 (Regular)	January, 1978
	0.15 (Premium)	January, 1982
Japan	0.19 (Premium - Minor Volume)	1980
Norway	0.15 (Regular)	September, 1980
	0.15 (Premium)	September, 1983
United Kingdom	0.15	1986
Germany, F.R.	0.15	January, 1976
Austria	0.15	April, 1982
EEC	0.40 - 0.15	January, 1981
United States	0.29	November, 1982

TABLE 15 LEAD CONTENT IN TOTAL GASOLINE PRODUCTION, 1981

Country	Grams Lead Per Litre
U.S.A.	0.13
Canada (actual)	0.28

TABLE 16 ALL NEW AUTOMOBILES RESTRICTED TO LEAD-FREE GASOLINE

Country	Effective Date
<u>Lead-Free Gasoline</u>	
U.S.A.	July, 1974
Japan	February, 1975
Australia	January, 1986

TABLE 17 LEAD ADDITIONS TO GASOLINE BY VARIOUS COUNTRIES, 1977

Country	Population	Estimated Lead Additions (million lb)	Average Lead Content (g/gal)
Canada	24 000 000	28.7	1.62 (pool)
U.S.A.	<u>218 000 000</u>	<u>354.8</u>	1.74 (pool)
Sub-Total	242 000 000	383.5	
Austria	7 500 000	2.6	1.81
Belgium	9 600 000	4.8	2.50
Denmark	4 900 000	1.5	1.41
France	50 800 000	28.0	2.50
Finland	4 700 000	2.6	3.18
Germany-Fed. Republic	61 200 000	9.9	0.68
Greece	8 800 000	2.6	3.82
Italy	54 500 000	18.7	2.88
Netherlands	13 100 000	4.6	1.81
Norway	3 900 000	2.0	1.81
Spain	32 300 000	8.4	2.72
Sweden	8 000 000	4.2	1.81
Switzerland	6 200 000	2.4	1.60
United Kingdom	<u>59 100 000</u>	<u>23.1</u>	2.04
Sub-Total	324 600 000	115.4	
Turkey	34 500 000	1.7	1.15
Australia	12 600 000	17.2	2.50
New Zealand	2 800 000	4.3	3.82
Japan	104 700 000	3.1	0.20
TOTAL	721 200 000	525.2	

3 REGULATION IMPACT ON INDUSTRY

Regulatory action to reduce the lead content of gasoline should impact the industrial sectors listed below:

- automotive manufacturing;
- petroleum refining;
- fuel additive manufacturing;
- primary lead; and
- automotive maintenance and spare parts manufacturing.

3.1 Automotive Manufacturing

3.1.1 Compression Ratio and Gasoline Octane Requirement. In the operation of a gasoline-powered engine, gasoline is evaporated and mixed with air in the carburetor. This gasoline-air mixture is then fed to the combustion chamber of the engine where it is compressed between 8 to 15 times atmospheric pressure (depending on the engine design), ignited, and the energy of combustion converted into useful power. The degree of compression is designated as the compression ratio of the engine. In practice, the engine efficiency increases rapidly with compression ratio from 4:1 to 10:1, increases slowly from 10:1 to 15:1 and decreases beyond 15:1.

To achieve satisfactory engine performance at a high compression ratio, it is necessary to use a high octane gasoline. Automotive and refinery engineers have considered these requirements with the result that modern automobile engines have a compression ratio in the range of 8:1 to 10:1 and the gasoline has a research octane number from 90 to 98.

The primary requirement of gasoline for an internal combustion engine is that it burns smoothly, without knocking, under the conditions existing in the combustion chamber of the engine so that the maximum amount of energy is liberated for use. The gasoline requirement is designated as the octane number. There are two analytical methods for determining the octane number of motor gasoline. The research octane number (RON) method and the motor octane number (MON) method. Both methods are in use. In general, the higher the octane number (RON, MON), the less the tendency of the gasoline to burn prematurely.

The octane number of gasoline can be increased either by adding a metal-containing compound, such as tetraethyl lead, or by blending gasoline with high octane

hydrocarbons, which are produced either at the refinery or by a chemical plant. Since 1926, the cheapest method to increase the octane number has been to blend a lead additive with the gasoline.

3.1.2 Automotive Exhaust Emissions. In the early 1970s, several countries developed regulations to reduce automotive exhaust emissions in order to combat major air pollution problems, particularly in urban centres. To meet the relatively stringent emission and fuel consumption standards enacted in the U.S., since 1975 U.S. automobile manufacturers have elected to use the catalytic converter or "after burner" in the exhaust system. The catalyst operates satisfactorily only with lead-free gasoline because lead damages the catalyst.

Under sustained pressure by the U.S. government, the automotive and petroleum refining industries have agreed to produce an engine with a compression ratio of 8:1 to 9.4:1 and a gasoline with an octane number of 91 to 92 as the appropriate compromise among refinery cost, engine efficiency, fuel consumption and emission standards.

Major Canadian automobile manufacturers were canvassed by the Department of Transport and it was established that the octane requirement for 1982 and 1983 automobiles would be 91 RON or $87 (R+M)/2$ for regular gasoline (24). It must be emphasized that the selection of the gasoline RON is a critical factor in developing petroleum refinery expansions and costs. Historically, the petroleum refining industry in the U.S. and Canada has produced a gasoline with a RON of 94. The U.S. industry has reduced this level to 92.5 in the last decade (25). It is assumed that the Canadian industry will also reduce the octane level in gasoline to 92 RON.

The Canadian General Standards Board has a regular gasoline specification (26) which requires a minimum RON of 92 and $(R+M)/2^*$ of 87. Minimum octane regular gasoline should be satisfactory for automobile operation. As a result of the preceding factors, a gasoline octane of 92 RON has been selected for the engineering assessment of the lead phase-down in gasoline program for Canada.

In the United States, some investigators contend that this extra octane (from 91 to 92) provides a margin of safety which should be a cost of doing business and not ascribable to the lead regulations (27).

* $(R+M)/2$ is Research Octane Number + Motor Octane Number

Currently, all new automobiles sold in the U.S. must use lead-free gasoline. In Canada, because of less stringent emission standards and a significant retail price differential between leaded and lead-free gasoline, several manufacturers have modified the U.S. automobile design (although maintaining the same compression ratio) to meet Canadian emission standards without a catalytic system and thus achieved a market or cost advantage over their competitors.

Recently, General Motors of Canada has advised several government officials that it will introduce in Canada a lead-tolerant engine option (lead-burner) for its 1983 Chevette, after producing automobiles to operate exclusively on lead-free gasoline for the past six years.

Manufacturers offering lead-burners are motivated by the lower price for leaded gasoline and/or the lower manufacturing cost of non-catalytic systems. However, vehicles meeting the more stringent U.S. emission standards have consistently shown lower fuel consumption than the equivalent Canadian vehicle using leaded gasoline. As a consequence, it is calculated that gasoline consumption in Canada has been 2.2% higher because of the use of leaded-gasoline-fueled automobiles (6 to 8% difference on 32% of the total vehicles) (28, 29). It is estimated that the future average difference in fuel economy between U.S. catalyst-equipped automobiles and Canadian lead-burners is about 4% (30).

Continued marketing of lower-cost leaded gasoline has also increased the practice of misfuelling, that is using leaded gasoline in catalyst-equipped vehicles. The misfuelling rate has been measured at 6 to 7%, which means that 6 to 7% of all vehicles are misfuelled all the time, or all vehicles are misfuelled for 6 to 7% of the time. In the first case, the catalyst is inoperative in 6 to 7% of the cars, which increases the emissions of hydrocarbons (HC) and carbon monoxide (CO) by a factor of five. For the Canadian fleet, this would increase nationwide emissions of HC and CO by 24%. For the latter case, all automotive catalytic systems are inoperative and this would increase the automotive emissions of HC and CO by 400%. The more probable case is that 6 to 7% of the automobiles are being misfuelled all the time; however, if leaded fuel were unavailable or sold at the same price as lead-free gasoline, there would be a reduction in misfuelling and thereby a reduction in automotive emissions of at least 20%.

3.1.3 Need for Leaded Gasoline. Engines for motorcycles, mopeds, 2-cycle lawn mowers, roto-tillers, automobiles and trucks have been designed to operate on lead-free

gasoline. The only exception appears to be heavy-duty truck engines that could have problems operating with lead-free gasoline. General Motors has indicated that 0.5 g Pb/gal are required in gasoline to avoid valve wear problems in heavy trucks (31).

3.2 Petroleum Refining Industry

In 1979, there were 34 petroleum refineries operating in Canada and these refineries have a range of processing capacities and complexities. The total refinery capacity is in excess of 2 million barrels (bbl) of crude oil per day and the distribution of refinery capacities by province is shown in Table 18. Half of the refining capacity is located in Ontario and Quebec and the refinery processing capacity varies from 3 000 to 250 000 bbl of crude oil per day.

Crude oil is processed by the refinery into various products, such as fuel oils, kerosene, diesel, gasoline and jet fuels. A simplified refinery flow diagram is shown in Figure 4 and it may be observed that the main components of motor gasolines come from the catalytic reforming unit, catalytic cracking unit, alkylation unit and the crude and vacuum units.

With normal operations, the refinery produces a gasoline with a RON of 86-89. To increase this octane number, the refiner has to produce higher octane products from the low octane fraction of gasoline with reforming, alkylation or isomerization facilities. For example, gasoline fractions with 70 RON can be converted to reformat with 102 RON, polymer gasoline with 96.5 RON or alkylates with 93 RON and isomerates with 83 RON. These conversion processes yield lower gasoline volumes and higher gaseous volumes and also require additional processing energy.

As mentioned previously, gasoline octane quality can also be increased by blending with fuel additives such as tetraethyl lead, alcohol or ether.

3.2.1 Historical Gasoline Demand. The Canadian gasoline production between 1930 and 1980 is given in Table 19.

TABLE 18 REFINERY CAPACITY IN CANADA, 1979 (Barrels per calendar day)

Province	Less than 10 000	10 000 to 30 000	30 000 to 50 000	50 000 to 100 000	More than 100 000	Total No.	Capacity
Nova Scotia		1		2		3	184 900
New Brunswick					1	1	250 000
Newfoundland		1				1	14 000
Quebec				6	1	7	617 400
Ontario			1	5	1	7	588 200
Saskatchewan			1			1	40 000
Manitoba			1			1	30 000
Alberta	1	2		1	1	5	271 700
British Columbia	1	3	3			7	168 500
Northwest Territories	1					1	2 900
Total No.	3	7	6	14	4	34	
Capacity	17 200	116 300	226 900	1 160 400	646 800		2 167 600

Note: The table does not include the Gulf refineries at Moose Jaw (Sask.) and Calgary (Alta.) because most of the production is asphalt. The Petrosar-complex at Sarnia is not included as it does not produce a full line of standard petroleum products. The Texaco refinery at Port Credit has not been included as it may not operate continuously or at capacity.

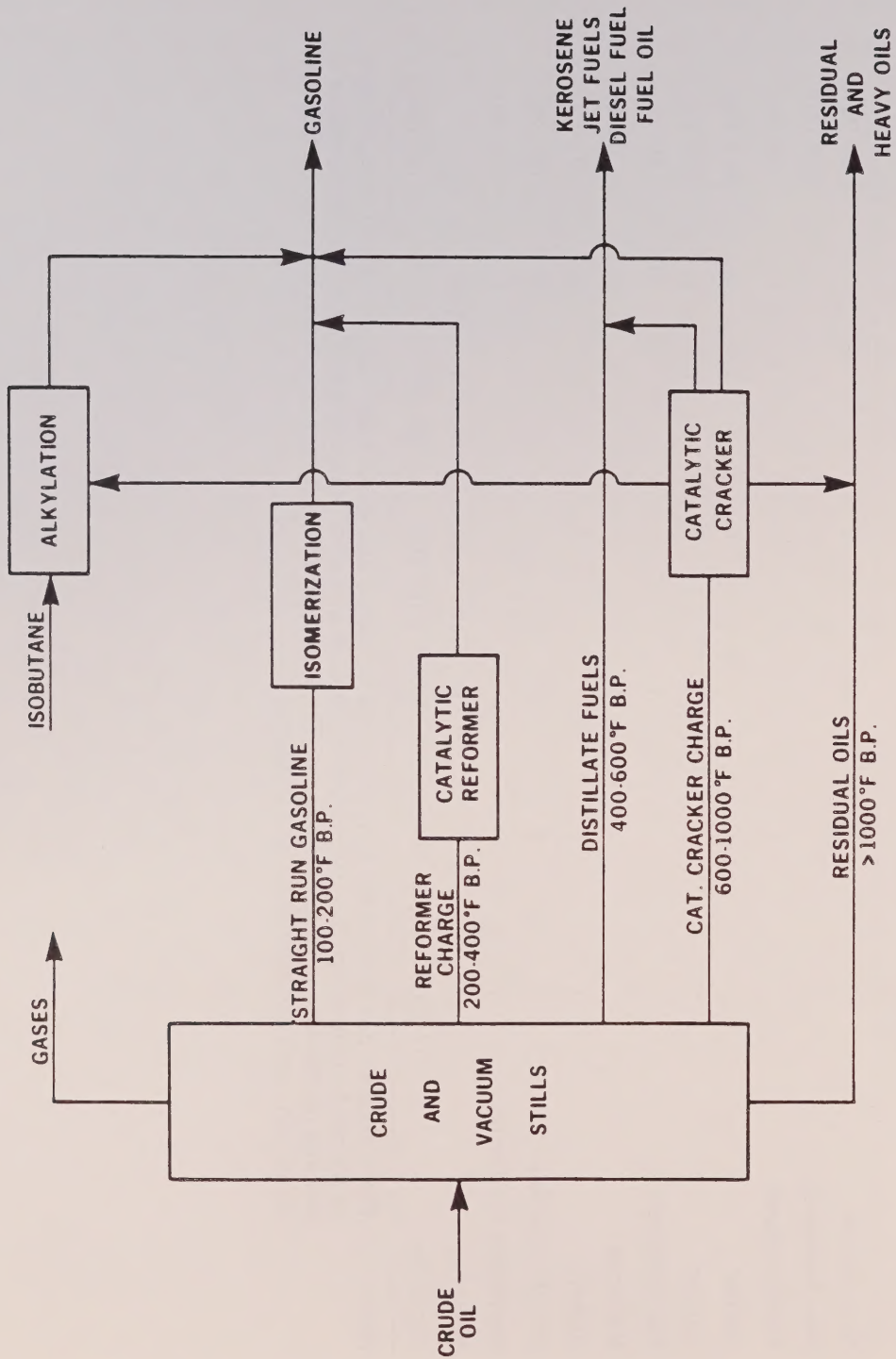


FIGURE 4 SIMPLIFIED REFINERY FLOW DIAGRAM

TABLE 19 CANADIAN GASOLINE PRODUCTION, 1930 TO 1980

Year	Production (million bbl/yr)
1930	16
1940	24
1950	50
1960	100
1970	164
1980	240

3.2.2 Historical Leaded and Lead-Free Gasoline Demand. In October 1973, Environment Canada promulgated regulations to ensure that lead-free gasoline was available for catalyst-equipped automobiles. These regulations stated that lead-free gasoline should not contain more than 0.06 g Pb/gal. In July 1974, Environment Canada promulgated regulations for leaded gasoline which established a maximum allowable lead concentration of 3.5 g/gal. To monitor the amount of lead added to gasoline, the petroleum refiners must submit quarterly reports on the volumes of leaded and lead-free gasoline produced, as well as the quantities of lead alkyls (expressed as lead) that are added to gasoline. These data for 1975 to 1981 are given in Tables 20 to 22, and gasoline production is shown in Figure 5.

Since 1975, the lead-free gasoline portion of the total gasoline pool has been increasing by about 6% per year and, in 1981, 38.5% of the total gasoline production was lead-free. Leaded gasoline production has decreased but the lead content for regular leaded gasoline has remained constant at about 2 g/gal.

TABLE 20 GASOLINE PRODUCTION IN CANADA, 1975 TO 1981

Year	Million Gallons				Lead-Free % of Total
	Premium	Regular	Lead-Free	Total	
1975	1 118	6 227	440	7 785	5.7
1976	1 016	5 957	1 001	7 974	12.6
1977	744	5 834	1 462	8 040	18.1
1978	401	5 648	1 865	7 914	22.5
1979	224	5 343	2 639	8 206	32.2
1980	107	5 217	3 076	8 400	36.6
1981	87	4 925	3 138	8 150	38.5

TABLE 21 LEAD ADDED TO CANADIAN GASOLINE

Year	Million Pounds			Total
	Premium	Regular	Lead-Free	
(1974 est.)	-	-	-	(39.8)
1975	6.9	27.9	-	34.8
1976	5.6	26.5	-	32.1
1977	4.1	24.6	-	28.7
1978	2.1	24.8	-	26.9
1979	1.0	25.3	-	26.3
1980	0.6	23.7	-	24.3
1981	0.6	22.5	-	23.1

TABLE 22 LEAD CONTENT OF GASOLINES IN CANADA

Year	Grams Per Gallon			Total Pool
	Premium	Regular	Lead-Free	
1975	2.80	2.03	-	2.03
1976	2.51	2.02	-	1.82
1977	2.52	1.91	-	1.62
1978	2.05	1.98	-	1.55
1979	1.99	2.12	-	1.45
1980	2.50	2.05	-	1.31
1981	3.09	2.07	-	1.29

3.2.3 Future Gasoline Demand. In 1980, the National Energy Board (NEB) undertook a comprehensive appraisal of the energy outlook for Canada. This appraisal included public hearings in major Canadian cities and 96 submissions were provided by the industry, provinces and other interested parties. From this information, the NEB published a forecast (32) of future fuel demand which is summarized in Table 23.

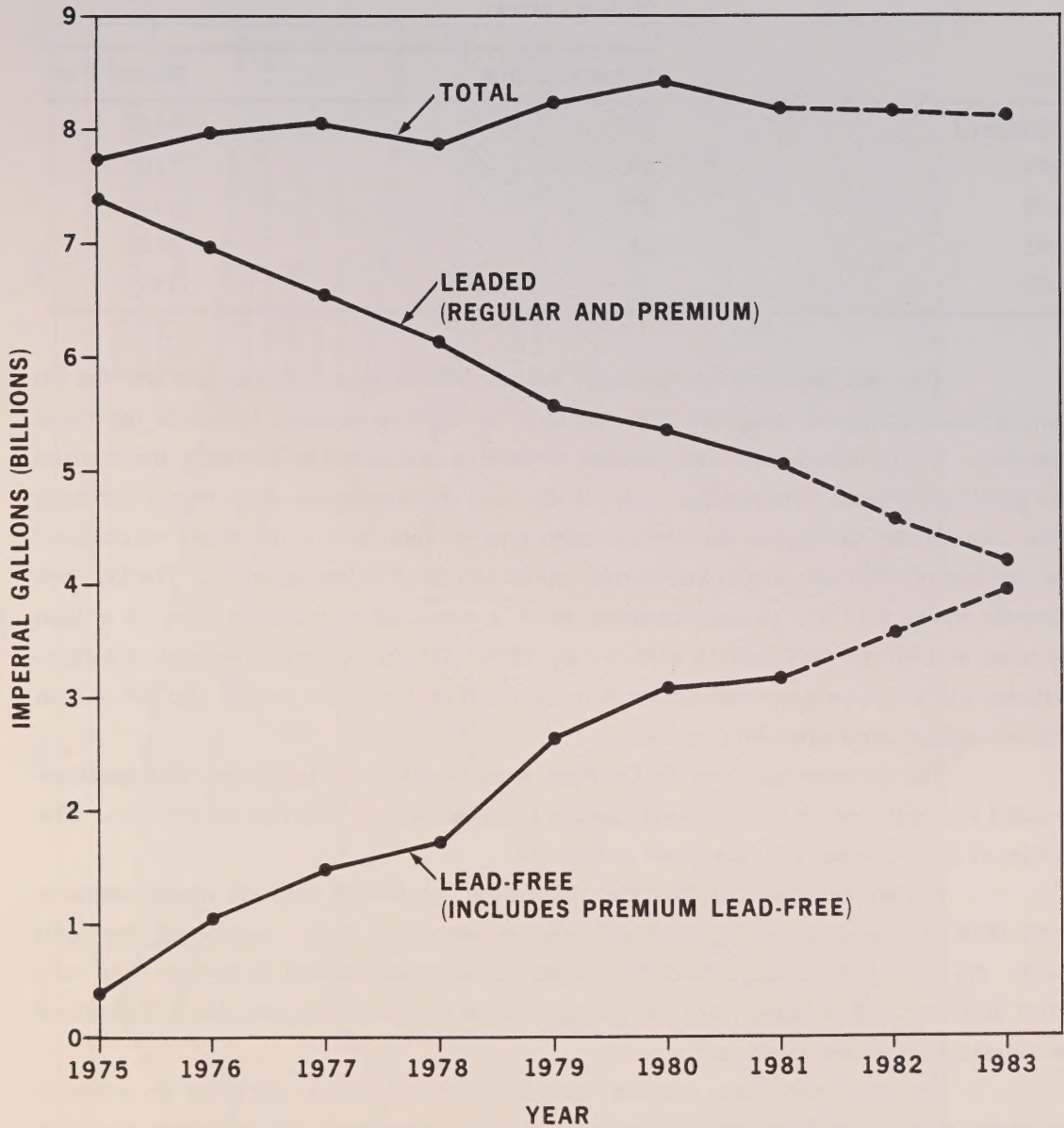


FIGURE 5 GASOLINE PRODUCTION IN CANADA

TABLE 23 FUTURE FUEL DEMAND IN CANADA

Year	Million Barrels	
	Motor Gasoline	Diesel Fuel
1980 (act.)	240	85
1985	235	110
1990	225	135
1995	215	165
2000	210	190

The NEB did not show forecasts for leaded and lead-free gasoline and the Du Pont ESCON computer program (33) was used to develop demand forecasts for these gasolines. In this model, the total gasoline demand is calculated by summing the demand for gasoline-powered automobiles, light trucks and medium/heavy-duty trucks for each year. To develop the annual demand for each type of vehicle it is necessary to consider the number of vehicles, annual kilometres driven and the fuel consumption. The Du Pont forecast shows that the gasoline-powered fleet is expected to increase from 14 million vehicles in 1982 to 16.5 million vehicles by 1990. Of these, approximately 12 million vehicles will be passenger automobiles, 4 million will be light-duty trucks and 0.4 million will be medium and heavy-duty trucks.

The assumptions used by Du Pont were modified by using the NEB gasoline-demand forecast and by Environment Canada's assessment of fuel use by vehicles. The results of this approach (34) are given in Figure 6.

It may be observed that the phase-down of leaded gasoline should continue until 1988 as new catalyst-equipped automobiles become a larger portion of the total fleet. At that time, about 87% of the passenger automobiles and light-duty (less than 6 000 lb) trucks will be using lead-free gasoline while the remaining vehicles will continue to operate with leaded gasoline.

For the truck fleet heavier than 6 000 lb, there are currently no emission standards that would force the use of the catalytic converter and lead-free gasoline. Therefore, almost 30% of the total gasoline pool would continue to be leaded gasoline.

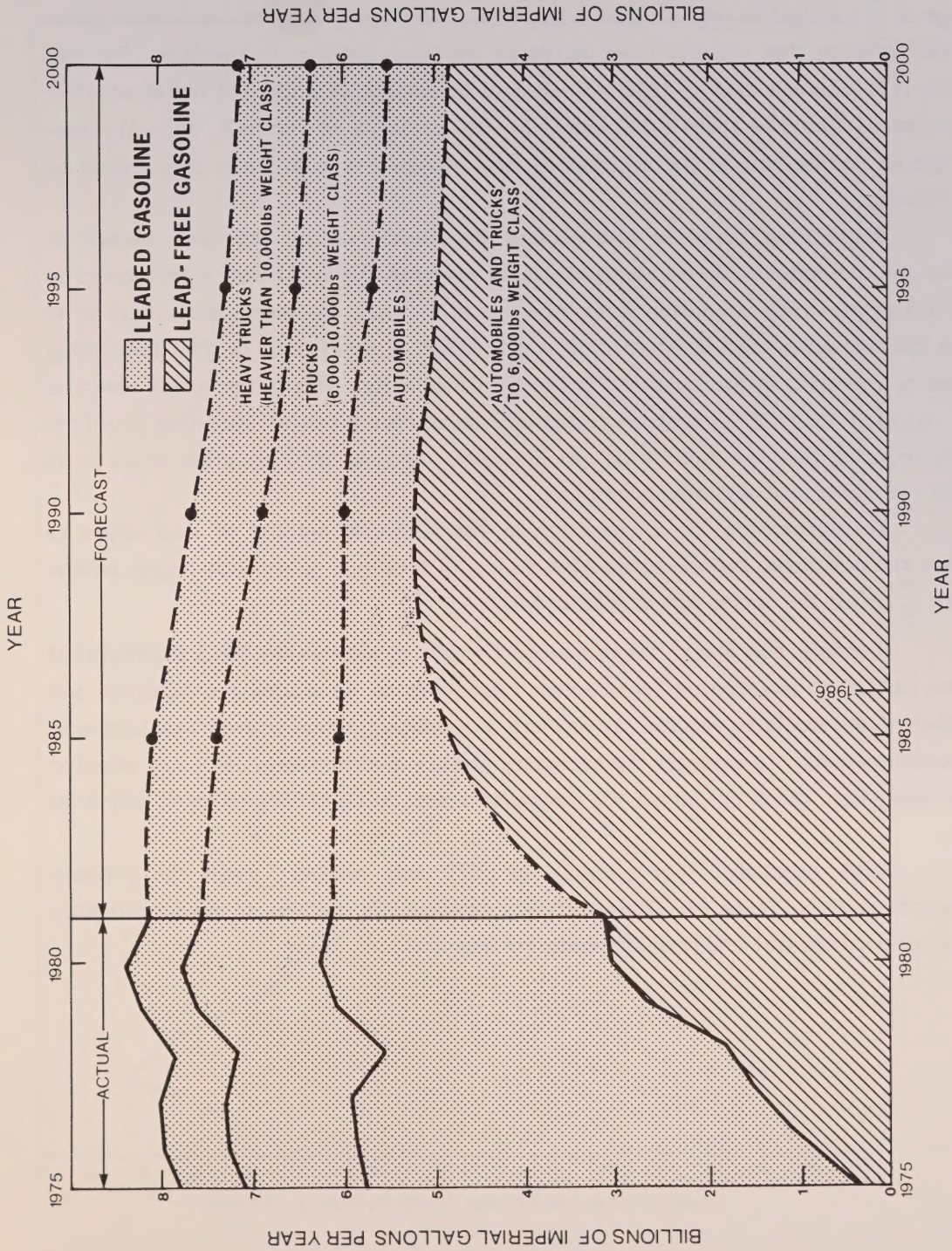


FIGURE 6 CANADIAN GASOLINE USAGE BY VEHICLE CLASS, 1975-2000

3.2.4 Lead Usage by Refiners. From 1975 to 1981 petroleum refiners added an average of 2 g Pb/gal to regular leaded gasoline. Preliminary data on lead consumption for 1982 indicate that refiners have increased the lead addition to gasoline. For this analysis, it is assumed that by 1986 refiners will be adding 3.5 g/gal and the automotive lead emissions should be about 8 000 tonnes in 1986 as shown on Figure 7. Natural phase-down should further reduce the automotive lead emissions and by 2000 they should be 6 000 tonnes.

Regulations could be promulgated that would reduce the lead content of gasoline and thus automotive lead emissions. For example, the lead content limit could be set at 1.3 g/gal, which is equivalent to the limit in the U.S. Another option would be to reduce the allowable lead limit to 0.68 g/gal, which is equivalent to the limit being adopted by countries in the European Economic Community. This latter option would be more stringent than EEC countries because Canada also produces lead-free gasoline, thereby reducing the lead used in the gasoline pool. Another control option would be to prohibit the use of lead additives in gasoline.

To compensate for a reduction in the allowable amount of lead added to gasoline, the petroleum refiner would have to install facilities to produce higher octane gasoline to offset the octane loss of lead additives.

3.2.5 Refinery Facilities. Environment Canada commissioned MHG International Limited (MHG), an engineering construction consultant, to determine the facilities and investments that would be required by refiners to produce gasoline with various allowable lead concentrations. To evaluate the necessary facility modifications, 1979 was selected as the base year, which permitted the computer model to be calibrated using historical data.

MHG concluded that gasoline in 1979 was produced from the refinery components given in Table 24. These refinery streams are blended to produce regular leaded, regular lead-free and premium lead-free gasoline.

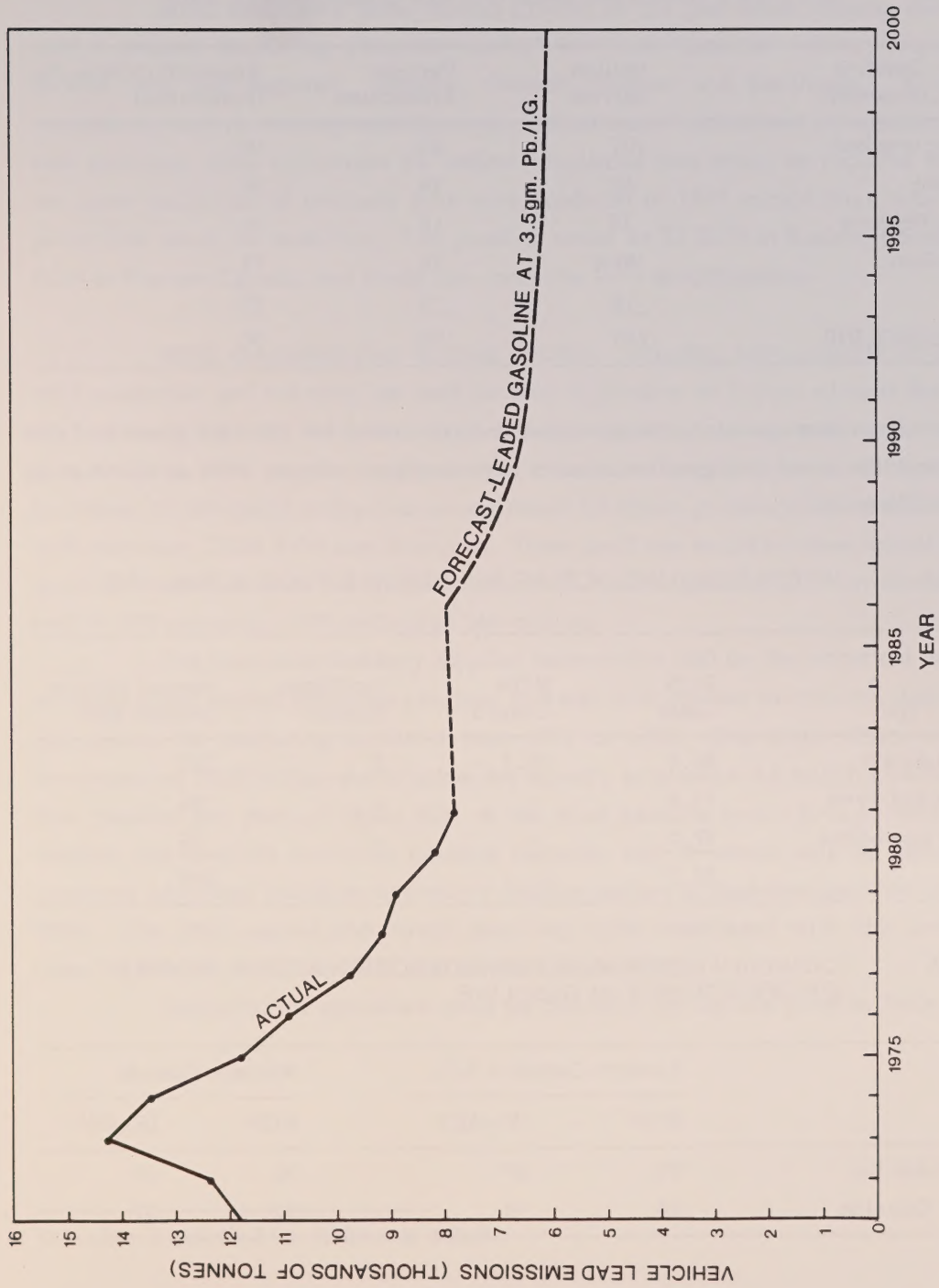


FIGURE 7 AUTOMOTIVE LEAD EMISSIONS IN CANADA

TABLE 24 REFINERY GASOLINE PRODUCTION COMPONENTS, 1979

Refinery Gasoline Stream Component	Million Barrels	Percent Production	Research Octane No. (Estimated)
Catalytic cracked	101	40	92
Reformate	60	24	98
Alkylate/Polymer	25	10	94
Straight-Run	49	20	71
Butane	<u>14</u>	<u>6</u>	<u>93</u>
TOTAL GASOLINE	249	100	90

The motor gasoline octane number and production for 1979 are given in Table 25. It should be noted that gasoline octanes exceeded the minimum RON as specified by the CGSB (Table 26).

TABLE 25 MOTOR GASOLINE OCTANE NUMBER AND PRODUCTION, 1979

Gasoline Type	RON Clear	RON Leaded	Lead Additions (g/gal)	Annual Volume (million bbl)
Regular Leaded	86.4	93.1	2	157
Regular Lead-Free	93.6	-	-	66
Premium Lead-Free	<u>97.5</u>	-	-	<u>26</u>
TOTAL	89.5			249

TABLE 26 CANADIAN GENERAL STANDARDS BOARD OCTANE NUMBER SPECIFICATIONS FOR GASOLINE

	Eastern Canada + B.C.		Western Canada	
	RON	(R+M)/2	RON	(R+M)/2
Regular Gasoline	92	87	90	85
Premium Gasoline	95	90	92	87

MHG completed three studies (35-37) on the petroleum refining industry and used a process simulating computer model* in which Canadian refinery capacity was divided into four regions: Western, Ontario, Quebec and Maritimes. With various constraints, such as existing capacities, production specifications and permissible levels of lead additions, MHG calculated the refinery facilities that would be required to produce the same quantities of products that were produced in 1979 except that total gasoline production would be lead-free. The gasoline would be 92 RON in Eastern Canada and 90 RON in Western Canada, and would also meet the $\frac{R+M}{2}$ specifications.

MHG concluded that existing refinery facilities were capable of producing 1979 quantities and reducing the lead content in gasoline to 1 g/gal without the need for any additional refinery facilities. Only refinery operating costs would be increased. If lead additives were completely phased out, it would be necessary to install isomerization facilities (73 000 bbl/d) to produce an additional 5.6 billion gallons/yr of lead-free gasoline with minimum CGSB RON specifications. These facilities would increase annual lead-free gasoline production from 2.6 billion gallons to 8.2 billion gallons, at an estimated capital cost (+ 30% accuracy, 1979 dollars) of \$64 million.

The petroleum industry supplied information (38) on the historical investment to produce and market lead-free gasoline; this was \$135 million for refinery facilities and \$85 million for marketing facilities from 1972 to 1980. This total refinery-marketing investment of \$220 million should allow the industry to produce 4.8 billion gallons of lead-free gasoline per year, or about 60% of the total gasoline pool. It is evident that the industry has prebuilt lead-free gasoline capacity and it would only be necessary to construct additional facilities to produce 3 billion gallons of lead-free gasoline required by 1986. The 1982 capital and direct operating costs associated with this incremental capacity are \$43 million and \$32 million/year, respectively.

Similarly, the estimated costs for the other options are given in Table 27.

* See Appendix I for additional details.

TABLE 27 CAPITAL AND DIRECT OPERATING COSTS FOR GASOLINE CONTAINING 1.3 AND 0.68 GRAMS OF LEAD PER GALLON

	Option	Option
	1.3 g Pb/gal	0.68 g Pb/gal
	<u>1982 Costs</u>	<u>1982 Costs</u>
Capital Costs	\$10 million	\$30 million
Direct Operating Costs	\$14 million/yr	\$22.5 million/yr

3.2.6 Other Studies. MHG prepared a study (37) on the costs to produce 5.6 billion gallons of lead-free gasoline per year with 94 RON, which is about two octane numbers higher than the minimum CGSB specification. For this case the estimated costs were \$886 million for capital equipment and \$369 million for direct annual operating expenses (in 1979 dollars). The incremental cost to displace lead from gasoline and produce 94 RON lead-free gasoline was estimated to be 1.47 cents per litre.

For the minimum CGSB RON case, MHG estimated costs (36) were \$64 million for capital equipment and \$53 million for direct annual operating expenses (in 1979 dollars). The incremental cost to displace lead from gasoline and produce the minimum RON lead-free gasoline was estimated to be 0.21 cents per litre.

To change leaded gasoline production to 94 RON lead-free gasoline, the estimated capital equipment cost was \$822 million and the direct annual operating cost was \$316 million higher than the minimum RON case. The additional refining cost to produce gasoline two octane numbers higher than is required would be 1.26 cents per litre.

The large capital cost difference between the two cases (\$822 million) results in an incremental gasoline cost of 1.3¢ per litre, which illustrates the sensitivity of gasoline costs to capital investment requirements.

Ethyl Canada Inc. also provided a detailed study on refinery costs (43). No cost estimates were provided for the minimum RON case, but refinery cost estimates were developed for the high RON cases. Ethyl developed unit costs for various processes based on discussions with knowledgeable Canadian refining personnel. It was assumed that the accuracy of the Ethyl cost estimates was in the $\pm 30\%$ range.

If lead additives in gasoline were prohibited, the refinery investment requirements were estimated to be (Table 28):

TABLE 28 ESTIMATES OF REFINERY CAPITAL COSTS FOR 94 RON GASOLINE

	MHG	Ethyl	
	1979	1979	1985
Refinery Capital Costs	\$886 million	\$466 million	\$1 073 million
RON	94	94	94

The major difference between the MHG and Ethyl estimates for 1979 is mainly due to estimates for reforming capacity expansions. MHG estimated a requirement of 229 000 barrels per day (bbl/d) reforming capacity while Ethyl estimated a requirement of only 155 000 bbl/d.

MHG indicated that it would be necessary to replace the existing reforming capacity with new reformers. However, Ethyl optimized refinery additions, such as upgrading the existing high-pressure reformers to more efficient low-pressure reformers and this reduced the capital cost estimate. It should also be noted that Ethyl's estimate of \$466 million included an investment of \$70 million for Eastern Canada and \$396 million for Western Canada. No provision was made in the Western Canada analysis of the effect of the lower octane requirement for gasoline production in Western Canada.

An A.D. Little report "The Impact of Lead Additive Regulations on the Petroleum Refinery Industry: Vol. 1 - Project Summary" was reviewed by the U.S. Environmental Protection Agency (27), which commented that:

"Fourth, it was assumed that unleaded gasoline would be manufactured at about 92 Research Octane Number (and at an 84 Motor Octane Number minimum), instead of the mandated 91 RON, to provide a margin of safety. Some investigators contend that this is a cost of doing business not ascribable to the lead regulations."

In view of the foregoing factors, it was concluded that although the engine octane requirement is 91 RON, nevertheless the 92 RON case will be used for this assessment. The 94 RON case is perceived by the refiners as being required for customer satisfaction and should be justified on this basis alone and should not be ascribed to lead regulations. This case has a higher energy penalty for refinery processing and the refinery capital costs are an order of magnitude higher than the costs of producing minimum RON gasoline.

3.2.7 Refinery Energy Penalty. The major portion of the energy used in a petroleum refinery is for processing operations and the balance is used for general purposes (such as water treating, tank heating and transfer pumping).

The industry supplied energy consumption data from which Statistics Canada published "Own Fuel Consumption" for Canadian petroleum refineries in 1979. The refineries used 129 000 bbl/d of fuel, which is equivalent to 6.7% of the total crude oil feed. Energy consumption is directly related to the feed rate and conversion in the processing units. MHG gives the energy requirement for each processing unit in Table 2-18 of its report (35).

To produce lead-free gasoline, the refiner must increase the octane number of gasoline with high octane hydrocarbons rather than with lead additives. Consequently, the refiner must increase the crude oil feed to produce high octane hydrocarbons and also to provide energy for the processing units. Crude oil requirements for the industry would be increased by 1.1 to 1.7%, but only a portion is consumed as processing energy and the remainder is converted into other products.

MHG calculated the incremental processing energy that would be required for the following cases:

- the maximum lead additions were 2 g/gal in leaded gasoline;
- the maximum lead additions were 1 g/gal in leaded gasoline;
- no lead was added and the entire production was lead-free regular gasoline which met the minimum specification set by the Canadian General Standards Board (CGSB);
- no lead was added and the entire production was regular lead-free gasoline that met the current industry specification; and
- no lead was added and the entire production was lead-free premium gasoline which met the CGSB specification.

The results of their calculations are summarized in Table 29.

TABLE 29 REFINERY ENERGY PENALTY, INCREMENTAL CRUDE OIL REQUIREMENTS

Lead Content (g/gal)	RON Quality	Type of Gasoline	Incremental Crude Requirement (bbl/d)	Incremental Processing Energy		
				Crude Equivalent (bbl/d)	Percent of Crude Feed	Percent as Gasoline Equivalent
2	94	Regular	4 900	2 000	0.1	0.3
1	94	Regular	23 400	5 800	0.3	0.9
0	94	Regular	32 300	11 600	0.6	1.8
0	92	Regular	21 200	9 600	0.5	1.5
0	95	Premium	65 100	19 300	1.0	3.0

For regular 92 RON lead-free gasoline, the refinery incremental crude oil requirement is 21 200 bbl/d but only 9 600 bbl/d are consumed as processing energy. Offsetting this penalty is the energy required to produce lead additives, which is estimated to be 0.1% crude, and therefore the net energy penalty is 0.4% of the crude. The gasoline equivalent of the net energy penalty is 1.2%, which can be offset by fuel savings from emission-controlled vehicles operating on lead-free gasoline. The impact of the energy penalty on crude is shown in Figure 8 and it may be observed that for a 2% energy penalty, the production life would be shortened by 0.4 years for 20 years crude oil reserves and 0.8 years for 40 years crude oil reserves. It is our technical judgement that the refinery energy penalty has been overemphasized and it should be considered as a non-issue.

It should also be noted (Table 20) that premium leaded gasoline production has declined from 14% of the total gasoline pool in 1975 to only 1% in 1981. Most refiners have replaced premium leaded gasoline with premium lead-free. This action was taken by the industry without any governmental intervention, with a resultant refinery energy penalty calculated to be 1% crude.

3.2.8 Alternatives. There are hydrocarbons other than refinery-produced products that refiners could use to increase the octane number of the gasoline pool. These high-octane chemicals, such as MTBE (methyl tertiary butyl ether) and alcohols (methanol or ethanol) can be used as blending compounds in proportions up to 15% of the gasoline.

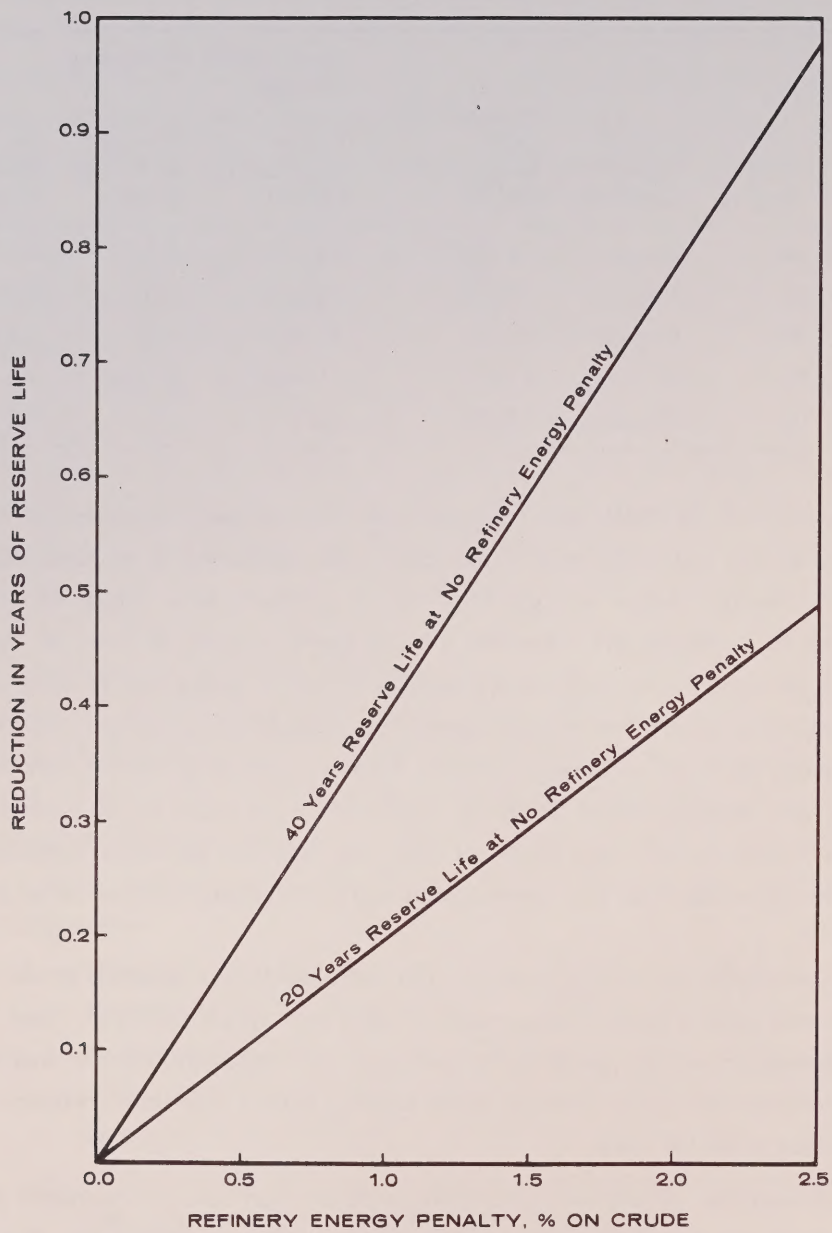


FIGURE 8 RESOURCE LIFE VERSUS REFINERY ENERGY PENALTY

(a) MTBE

Natural gas can be used to produce methanol and isobutylene, which are then reacted to form MTBE.

The use of MTBE is increasing rapidly in Europe and the U.S. to boost the octane number of the gasoline pool. The RON range of MTBE blended gasolines is 115-135 and the actual blending number generally rises as the gasoline base octane number decreases and the saturates content increases. MTBE has a low boiling point (55°C) and its addition improves the octane number of the high volatile component of gasoline. In engine performance, MTBE blended gasolines compared with refinery gasolines show no difference in gasoline consumption or horsepower, marked improvement in road octane number at low speed, no difference in evaporation losses, and no problems with icing or corrosion.

(b) Alcohols

Methanol can be produced from natural gas and ethanol from grains. Celanese Ltd. is constructing the largest methanol plant in the world in Edmonton, Alberta. When this plant is completed, a portion of its production will be sold to firm markets but there should be sufficient uncommitted methanol to satisfy the demand for the Canadian gasoline pool.

Methanol and ethanol are both very satisfactory fuels for internal combustion engines. The RON rating of methanol is 112 and ethanol is 110. Combustion of these alcohols in automobiles results in low emissions. One disadvantage is that the energy content of alcohols is lower than gasoline. Thus, for a given travel radius, a methanol fuel tank has to be 65% larger than that for gasoline. Other problems with methanol are the cold starting and the separation of methanol from gasoline in the presence of water. These problems seem to have been overcome by adding a 4-5% methanol with 4-5% cosolvent such as a heavy alcohol.

These chemicals are better named as gasoline extenders rather than additives. As such, the use of these extenders would support the aims of the National Energy Program to reduce crude oil imports and also to convert to natural gas use.

3.3 Fuel Additive Manufacturing Industry

Any regulations to phase down the use of lead in gasoline would have an impact on the fuel additive manufacturers. Environment Canada commissioned MHG International Ltd. to undertake a study on the incremental capital and operating costs to

the lead antiknock manufacturers associated with the reduction in the amount of lead additive in gasoline (39).

MHG concluded that the future of the lead additive manufacturing industry is not very promising. It was concluded that even without any further regulatory action, the consumption of lead antiknock additives will fall to about half the 1979 amount by the early 1990s because of the increasing demand for lead-free gasoline.

There are only two Canadian lead additive manufacturers, Ethyl Canada at Sarnia, Ontario, and Du Pont Canada at Maitland, Ontario. These plants have a combined capacity of about 100 million pounds per year and the companies currently are operating at two-thirds of total capacity.

If the lead regulations were changed to permit 1.3 g/gal in 1986, sales would be reduced to 16% total capacity. If the regulations were set at 0.68 g/gal, lead additive production would be reduced to 10% of total capacity.

Lead phase-out in gasoline would close down the two manufacturing facilities and result in a capital expenditure of \$5-6 million for the decommissioning of facilities used in the production and marketing of lead additives.

The effect of the regulatory measure to phase-out lead in gasoline would result in the loss of 300 jobs at the two plants. It is expected that natural phase-down will also result in job losses for these manufacturers. A more detailed study of this industry will be completed for the socio-economic impact assessment.

3.4 Automotive Parts and Service Industry

Environment Canada commissioned the consultant, Hickling-Partners Inc., to consider the impacts for this industrial sector (40).

The size and scope of the impact of proposed leaded gasoline regulations are traced to the manufacturing and retail levels. Any change to regulations that reduces lead will have no measurable impact on the consumer or the parts/service industry. Only the complete elimination of lead alkyls from gasoline would result in savings or benefits for the consumer.

The consultant concluded that there were potential savings in maintenance costs if the consumer operates an automobile on lead-free gasoline. These savings are due to reduced maintenance for mufflers and spark plugs and are estimated to be \$1 per 1 000 km over a lifetime distance of 160 000 km.

The cumulative effect on the industry from 1985 to 1990 would be a reduction in retail sales of \$230 million of which \$170 million would be from a reduction in muffler

sales and \$60 million from reduced spark plug sales. Apart from the decreased sales revenue, no other significant implication was found for the industry. It should be noted that natural phase-down of leaded gasoline will have about a 60% effect on these sales and the remaining 40% would be due to lead phase-out in gasoline.

There would be about 200 jobs lost for these industries. A more detailed study of this industry will be completed for the socio-economic impact assessment (SEIA).

3.5 Primary Lead Industry

Production of lead from Canadian ores increased from approximately 200 000 tons in the 1950s to nearly 400 000 tons in the early 1970s even though world consumption remained relatively stable. Canadian consumption has been increasing steadily but it is only about one quarter of Canadian production. In 1981, about 12 000 tons of lead were used in the production of leaded gasoline. Consequently, lead phase-out in gasoline would reduce demand for Canadian lead by approximately 3% and, therefore, the lead additive market is a small component of lead production.

The major market for lead is for lead storage batteries and this market will continue unless technological progress makes the lead-acid battery obsolete. This market could also grow if electric vehicles were used more extensively as a second vehicle or a commuter vehicle.

Although a more detailed study for this industry will be completed for the SEIA, it may be concluded that the market in Canada for lead in tetraethyl and tetramethyl lead has no significant impact on the viability of Canada's lead mining industry.

4

AUTOMOTIVE LEAD EMISSION CONTROL

Lead emissions from automobiles in 1978 were estimated to be 9 200 tonnes or 63% of the total atmospheric lead emissions in Canada. If there are no changes in the current regulations, it is expected that automotive lead emissions should decrease to 6 000 tonnes by 2000. This emission reduction is due to the strategy of most automobile manufacturers to produce a catalyst-equipped automobile for the entire North American market. For Canada, however, Chrysler has continued to manufacture automobiles that operate on leaded gasoline and General Motors intends to produce a 1983 model which also operates on leaded gasoline.

4.1**Control Options**

There are two basic legislative approaches available to the federal government to control automotive lead emissions to the environment:

- to reduce or eliminate the use of lead additives in gasoline using the authority of the Minister of the Environment under the Clean Air Act; or
- to regulate maximum permissible lead emissions from vehicle exhausts using the authority of the Minister of Transport under the Motor Vehicle Safety Act.

For these regulatory strategies, we have considered an implementation date of January 1986, and six control options:

- Option 1: The status quo is the base case which permits the use of 3.5 g Pb/gal. For this case, it is expected that lead emissions will decrease gradually because of the increasing market for lead-free gasoline.
- Option 2: Promulgate a leaded gasoline regulation under the Clean Air Act which would permit a maximum addition of 1.3 g Pb/gal. This is essentially the same limit that was announced by U.S. EPA on November 1, 1982.
- Option 3: Promulgate a leaded gasoline regulation which would permit a maximum addition of 0.68 g Pb/gal. This is similar to the limit being adopted by most countries in the European Economic Community.
- Option 4: Promulgate a regulation which would not permit any lead additions to gasoline. Only lead-free gasoline would be available for all automotive vehicles.

Option 5: Promulgate a regulation which would require the use of lead-free gasoline for all automotive vehicles except heavy trucks. The regulation would permit the addition of 0.68 g Pb/gal in gasoline for use in heavy trucks.

Option 6: Promulgate a regulation under the Motor Vehicle Safety Act which would require the installation of a lead trap on all those vehicles manufactured for sale after 1985 which are designed to operate on leaded gasoline. Automotive exhaust emission standards would be set in grams of lead per kilometre.

These options are discussed in the following subsections and further details are given in Appendix II. Each option has been evaluated and compared with Option 1 to assess the incremental:

- reduction of lead emissions;
- control costs; and
- benefits.

4.2 Assessment and Conclusions

4.2.1 Automotive Lead Emissions. The forecast gasoline production (Section 3) and the various control reductions for each option were used to estimate the annual automotive lead emissions from 1986 to 2000.

TABLE 30 CUMULATIVE LEAD EMISSIONS, 1986 TO 2000, FOR VARIOUS CONTROL OPTIONS

		Lead Emissions Cumulative from 1986 to 2000	
		(tonnes)	Control (%)
Option 1	Status quo - 3.5 g Pb/gal	98 000	-
Option 2	1.3 g Pb/gal	36 000	63
Option 3	0.68 g Pb/gal	19 000	81
Option 4	Lead-free	0	100
Option 5	Lead-free and 0.68 g Pb/gal for heavy trucks	6 000	94
Option 6	Lead traps for new vehicles	61 000	39

These emission reductions are shown for all options in Figure 9 and for certain options in Figures 10, 11 and 12. Lead emissions would be reduced for Options 3, 4 and 5 by 81, 100 and 94% during the 1982-2000 period, reductions beginning in 1986. The least effective emission reduction would be for Option 6, because lead traps would be installed only on post-1985 vehicles operating with leaded gasoline. It would be at least a decade before all vehicles using leaded gasoline are controlled and emissions would decrease gradually until 1999, at which time automotive lead emissions should be controlled by about 66% (the lead-trap efficiency).

4.2.2 Capital and Operating Costs

4.2.2.1 Refinery capital investment. Gasoline octane levels would be affected if control Options 2 to 5 (inclusive) were implemented and these gasoline octane levels would have to be restored with high-octane hydrocarbons produced by the refiner. As discussed in Section 3, the refinery capital investment to convert 70% of the gasoline pool from leaded to lead-free gasoline was estimated to be \$64 million (in 1979 dollars). Some of these facilities have been installed to meet the market demand in 1986 and only 30% of the total gasoline pool would need to be converted from leaded to lead-free gasoline. Prorating this lower requirement and upgrading 1979 costs to 1982, it is estimated that the capital investment would be \$43 million for Option 4. A similar approach was used to estimate the refinery capital investment for Options 2, 3 and 5, in which the permissible lead level in the leaded gasoline is reduced and/or eliminated (Table 31). The change in refinery facilities between Options 4 and 5 is so insignificant that the same capital investment estimate was used for both.

TABLE 31 ESTIMATED REFINERY CAPITAL INVESTMENT COSTS FOR CONTROL OPTIONS 2, 3, 4 AND 5

		Estimated Capital Investment (\$ million, 1982)
Option 2	1.3 g Pb/gal	19
Option 3	0.68 g Pb/gal	30
Option 4	Lead-free	43
Option 5	Lead-free and 0.68 g Pb/gal for heavy trucks	43

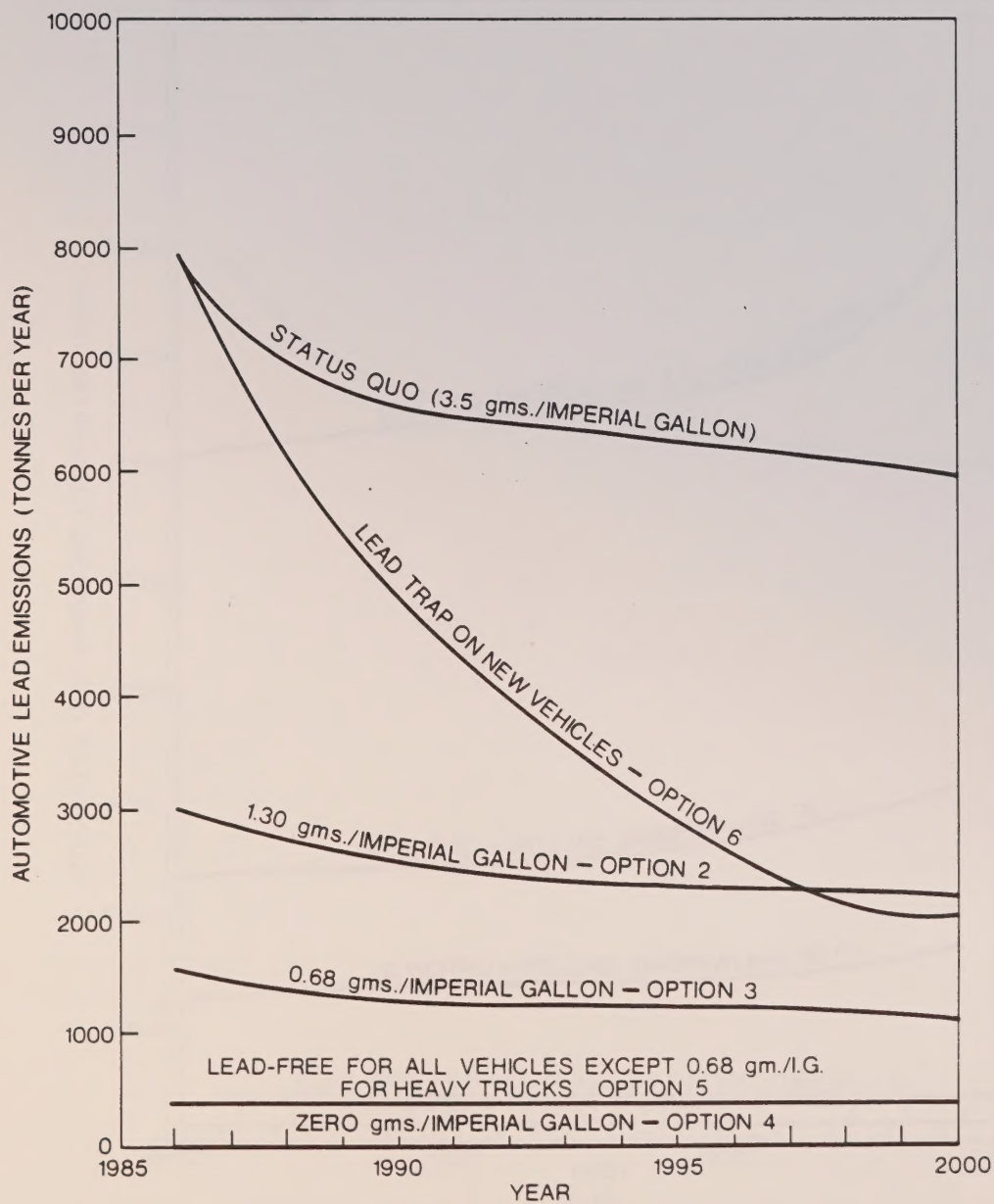


FIGURE 9

FORECAST OF AUTOMOTIVE LEAD EMISSIONS FOR VARIOUS
OPTIONS

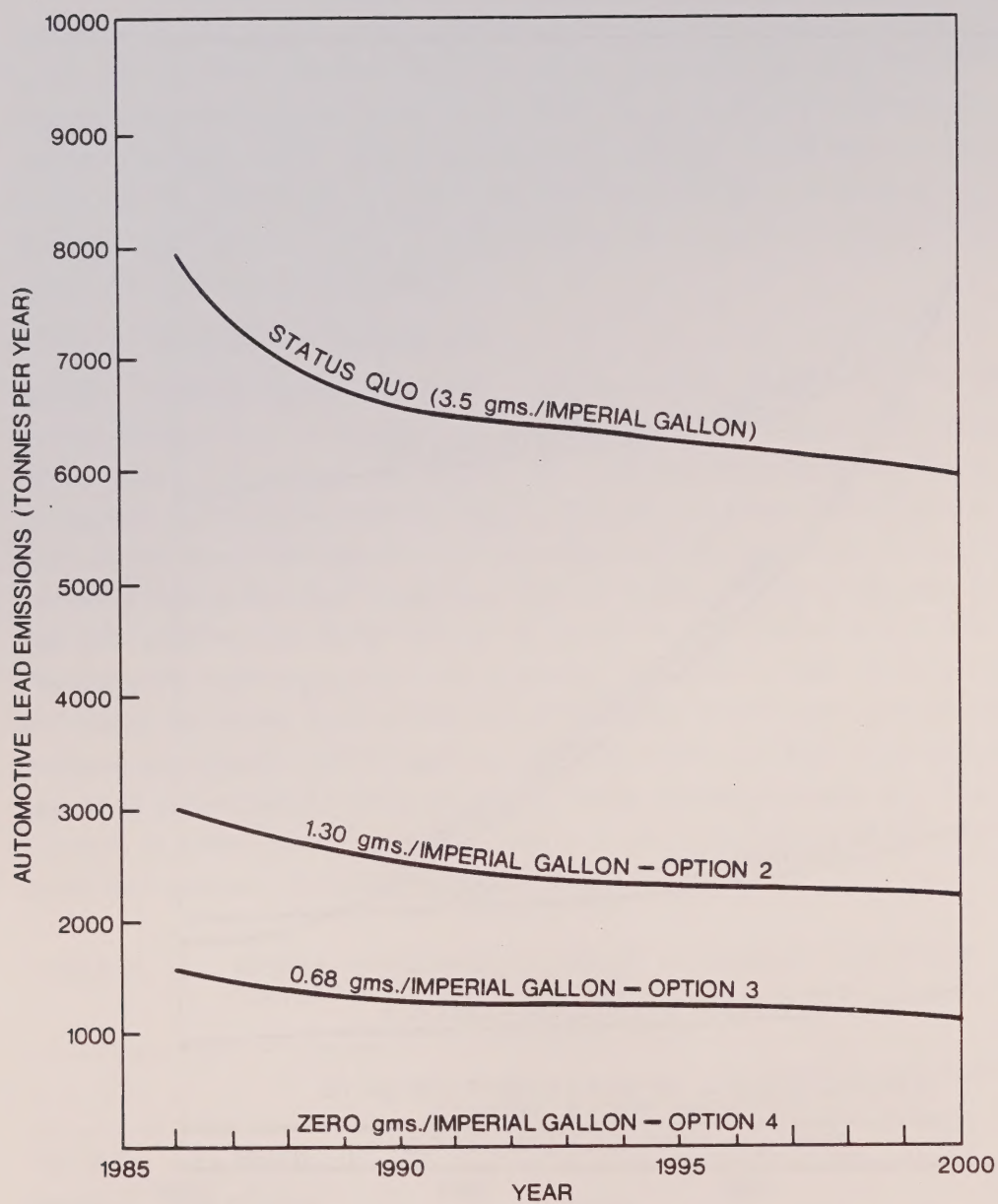


FIGURE 10 FORECAST OF AUTOMOTIVE LEAD EMISSIONS WITH VARIOUS ALLOWABLE LEAD CONTENTS IN GASOLINE

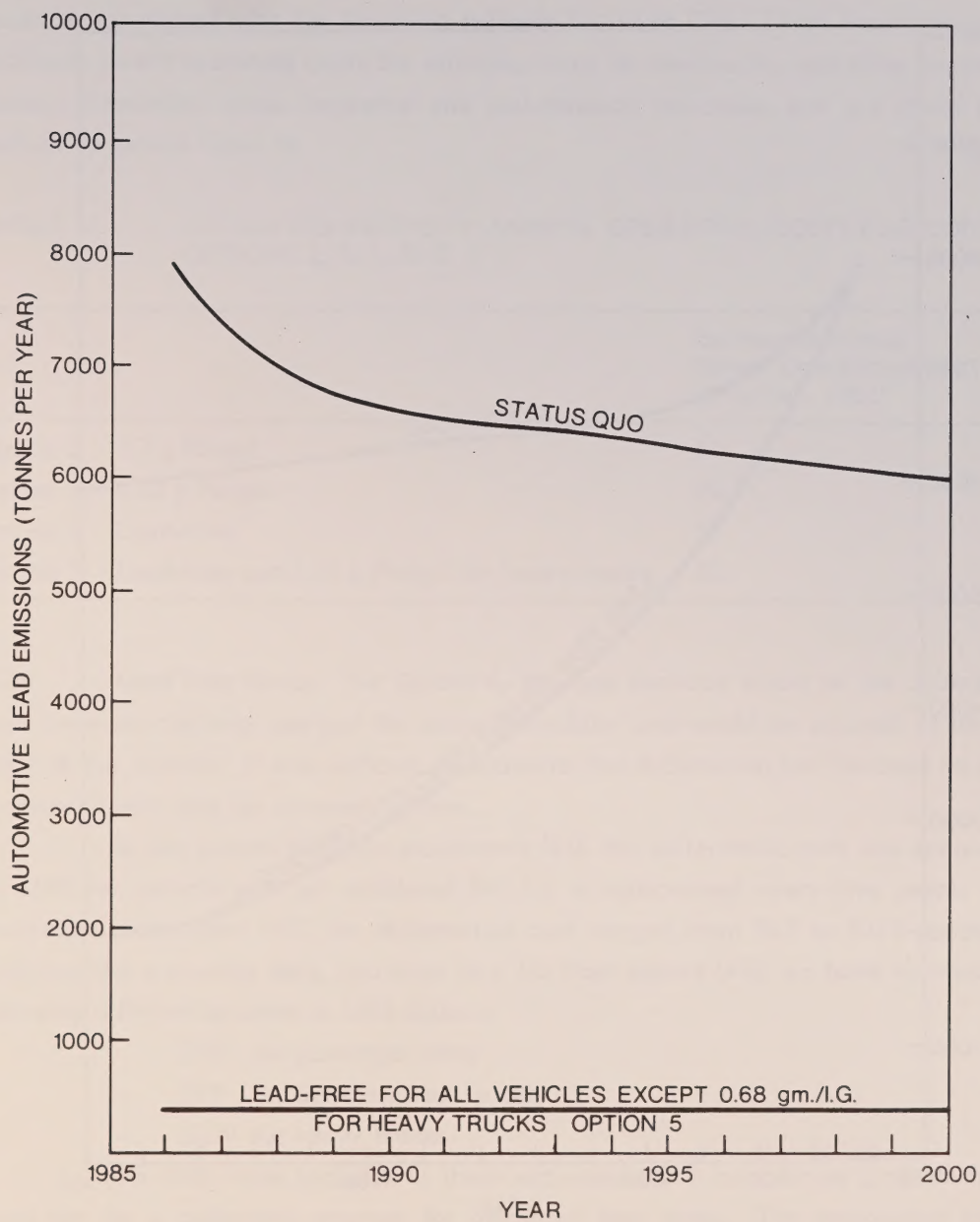


FIGURE 11 FORECAST OF AUTOMOTIVE LEAD EMISSIONS WITH LEADED GASOLINE (0.68 g/gal) ALLOWED FOR HEAVY TRUCKS

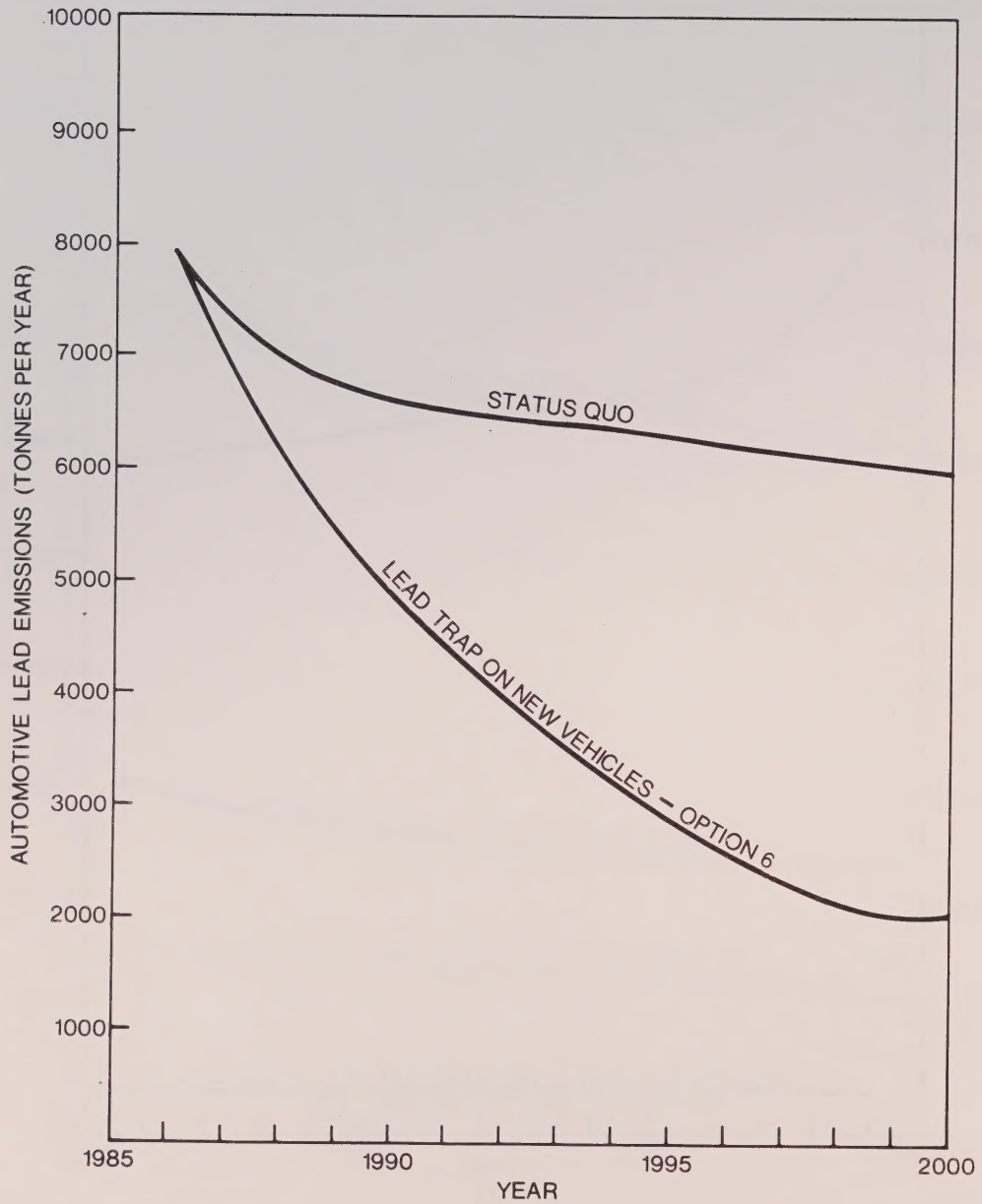


FIGURE 12 FORECAST OF AUTOMOTIVE LEAD EMISSIONS FOR STATUS QUO AND FOR LEAD TRAP INSTALLATIONS

4.2.3 Refinery Operating Costs. MHG developed operating cost estimates that would be associated with the expanded refinery facilities (36). These estimates included increased direct operating costs for utilities, crude oil feedstocks, operating-maintenance labour, chemicals, taxes, insurance and maintenance materials, and are given for the various options in Table 32.

TABLE 32 ESTIMATED REFINERY ANNUAL OPERATING COSTS FOR CONTROL OPTIONS 2, 3, 4, AND 5

		Estimated Annual Direct Operating Cost (\$ million, 1982)
Option 2	1.3 g Pb/gal	14
Option 3	0.68 g Pb/gal	22.5
Option 4	Lead-free	32
Option 5	Lead-free and 0.68 g Pb/gal for heavy trucks	32

4.2.4 Lead Trap Costs. For Option 6, the cost incurred would be the difference in costs between the lead trap and the standard muffler and would be included in the retail price of the vehicle. It was difficult to estimate this differential cost because no one has produced a lead trap for commercial use.

In the United Kingdom assessment (41), the differential cost was estimated to be \$100 per vehicle with an additional \$40 for a replacement every five years. In the Australian assessment (42) the differential cost ranged from \$67 to \$113 per vehicle. Utilizing the preceding data, and data in a Du Pont report (43), we have estimated the following differential costs in 1982 dollars:

- \$50 for passenger cars;
- \$75 for light/medium trucks;
- \$100 for heavy trucks.

No costs were included in these estimates for a compliance program for lead traps nor for a collection program for discarded lead traps. The compliance program would be extensive because about 250 000 new vehicles would be equipped with

lead traps every year. After a decade, the same number of discarded lead traps would have to be collected every year.

From the foregoing, and the vehicle population (33), the total annual differential cost for lead traps was estimated to be \$19.2 million (Table 33).

TABLE 33 ESTIMATED ANNUAL DIFFERENTIAL COST FOR LEAD TRAPS

		Annual Differential Cost (\$ million, 1982)
Option 6	<u>Lead Traps</u>	
	Passenger Cars	6.8
	Light/Medium Trucks	8.4
	Heavy Trucks	4.0
TOTAL		19.2

4.2.5 Benefits. Implementation of lead-free gasoline Options 4 or 5 would result in benefits for the motorist through fuel and maintenance savings. It is assumed that all new automobiles in 1986 and following years will use lead-free fuel, thereby displacing lead-tolerant cars (13% of new car market), and that these cars will achieve 4% better fuel economy than the lead-tolerant cars.

In addition, there would be maintenance savings for existing vehicles operating on leaded gasoline that would switch to lead-free gasoline in 1986, that is, 13% of the passenger cars/light trucks and all trucks heavier than 6 000 lb.

Fuel consumption and maintenance savings for Option 5 would be the same as for Option 4 except that there would be no maintenance savings for heavy trucks. Estimated savings or benefits for these options from 1986 to 2000 are given in Table 34.

TABLE 34 OPERATING COST SAVINGS FOR OPTIONS 4 AND 5

	Option 4 (\$ million)	Option 5 (\$ million)
<u>Range Per Year</u>		
Fuel Savings	7-20	7-20
Maintenance Savings	13-100	10-75
<u>1986-2000</u>		
Fuel Savings	775	775
Maintenance Savings	1 099	808
TOTAL	1 874	1 583

4.2.6 Incremental Costs and Benefits. Using the status quo as a base case, the incremental lead emission reductions, control costs and benefits for the five options for the period 1982 to 2000 are shown in Appendix II and are summarized in Table 35. In this assessment, future costs and benefits have been discounted at an interest rate of 10% to show the present-value (1982) costs and benefits.

TABLE 35 LEAD EMISSION REDUCTIONS, COSTS AND BENEFITS FOR CONTROL OPTIONS

Option	Lead Emission Reduction (tonnes)	Present Value 1982 Net Benefits or (Costs) (\$ million)	Cost Effectiveness Benefit or (Cost) (\$ per tonne lead)
1 Status quo 3.5 g Pb/gal	0	0	-
2 1.3 g Pb/gal	62 000	(108)	(1 740)
3 0.68 g Pb/gal	79 000	(172)	(2 180)
4 Lead-free	98 000	346	3 530
5 Lead-free except 0.68 g Pb/gal for heavy trucks	92 000	256	2 780
6 Lead trap	38 000	(110)	(2 890)

4.2.7 Benefit/Cost Ratio. Each control option has an environmental benefit which has not been quantified during our studies. But the quantifiable benefit/cost ratios for Options 4 and 5 are as follows:

	<u>Benefit/Cost Ratio</u>
Option 4	2.4
Option 5	2.0

4.2.8 Conclusions. From the foregoing analysis, the least effective strategy is the lead trap option. It would be 13 years before all vehicles operating on leaded gasoline would be equipped with a trap to control automotive lead emissions. This option would also be undesirable if future automotive emission standards were more restrictive and could only be met by using the catalytic converter control technology. In addition, an expensive and complicated enforcement-collection program for lead traps would be required.

A leaded gasoline regulation could become effective in 1986 and lead emissions could be decreased by 63 to 81% by reducing the allowable lead content to 1.3 or 0.68 g Pb/gal. These options would result in environmental benefits.

Eliminating lead from gasoline would result in higher environmental benefits and would also result in benefits to the consumer due to lower automotive maintenance costs. The lead-free gasoline Options 4 and 5 are relatively comparable for environmental and consumer benefits. Option 5 would require lead-free gasoline to be used in all automotive vehicles except heavy trucks. Automobile manufacturers have identified a need for low-lead gasoline in heavy trucks to prevent valve wear.

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APPENDICES

APPENDIX I MHG METHODOLOGY FOR REFINERY COMPUTER PROGRAM

MHG developed a computer simulation model from which the additional refinery processing and energy requirements were calculated to meet a range of lead levels in leaded gasoline and still produce petroleum products in accordance with 1979 quantities. MHG considered lead levels of 2, 1 and 0 g Pb/gal for regular leaded gasoline.

Canadian refineries were divided into four regions: Atlantic, Quebec, Ontario and Western. The capacity of each process unit in each of the four composite refineries (one for each region) was taken to be equal to the installed capacities of all the units within that region.

The computer model uses techniques to simulate refinery processes (Figure 13), and uses material weight balance and product property calculations. No economic data were incorporated into the program.

In completing the study cases, the computer program was solved iteratively by means of user interaction. In effect, the optimizing procedure, which would be performed by a linear programming algorithm, was done manually for the MHG computer model. The optimizing criteria used in each case study were:

- maximum utilization of existing process units;
- minimum crude oil consumption.

(Note: Increased crude oil consumption is disadvantageous to Canada for economic reasons and this was considered to be the prime factor in the determination of an optimal solution.)

A fairly systematic approach was used to develop each case. The various routines that were calculated are illustrated in Figure 14 and are summarized below:

1. Data gathering - the crude oil feed diets, product slates and unit capacities were determined for each region in every case study.
2. Crude blending routine (blocks 1 to 3 in Figure 14) - the computer program breaks down each of the crudes into individual components and blends them in the specified proportions.
3. Material balance routing (blocks 4 to 10) - sufficient data were entered to close the material balance, such as product slates, feed rates to units, some True Boiling Point (TBP) cut points, catalytic cracker conversion and characterization factor of the naphtha feed. The data are processed through a program which outputs

estimates of yields from the process units and completes the material balance as well as the flow rates for all the streams shown in Figure 13.

4. User inspection of material balance results (block 11) are reviewed against the following constraints:

- unit capacities;
- limitations on certain operating variables such as cut points and unit turndowns.

If these constraints are not satisfied, routine 3 is repeated with modified input data.

5. Product quality routine (blocks 12 and 13) - additional data (including gasoline lead concentration) is entered by the user and product qualities are then computed.
6. User inspection of product qualities (block 14) - estimated product qualities are reviewed against the listed product specifications. If the product specifications are not satisfied, the analysis is returned to either routine 3 or 5.
7. User review optimizing criteria - when a solution is found to satisfy all the constraints, it is then reviewed to ensure that it is more or less optimal in terms of the criteria mentioned above. In general, cases were repeated in the optimal direction until one or more slacks between a variable and its constraints were eliminated.

The contractor developed simulator capacities for the refinery processing units from relevant publications in periodicals and from additional clarification by contacting the representatives of the oil industry.

The current refinery complexes do not have isomerization units in operation which are evidently needed to produce all lead-free motor gasoline. In order to limit the complexity of the simulators, the hydrocracking and fluid cracking capacity were included in the computer world as one capacity for catalytic cracking. This combination would probably result in conservative gasoline yields as the model treats this as conventional fluid catalytic cracking operation.

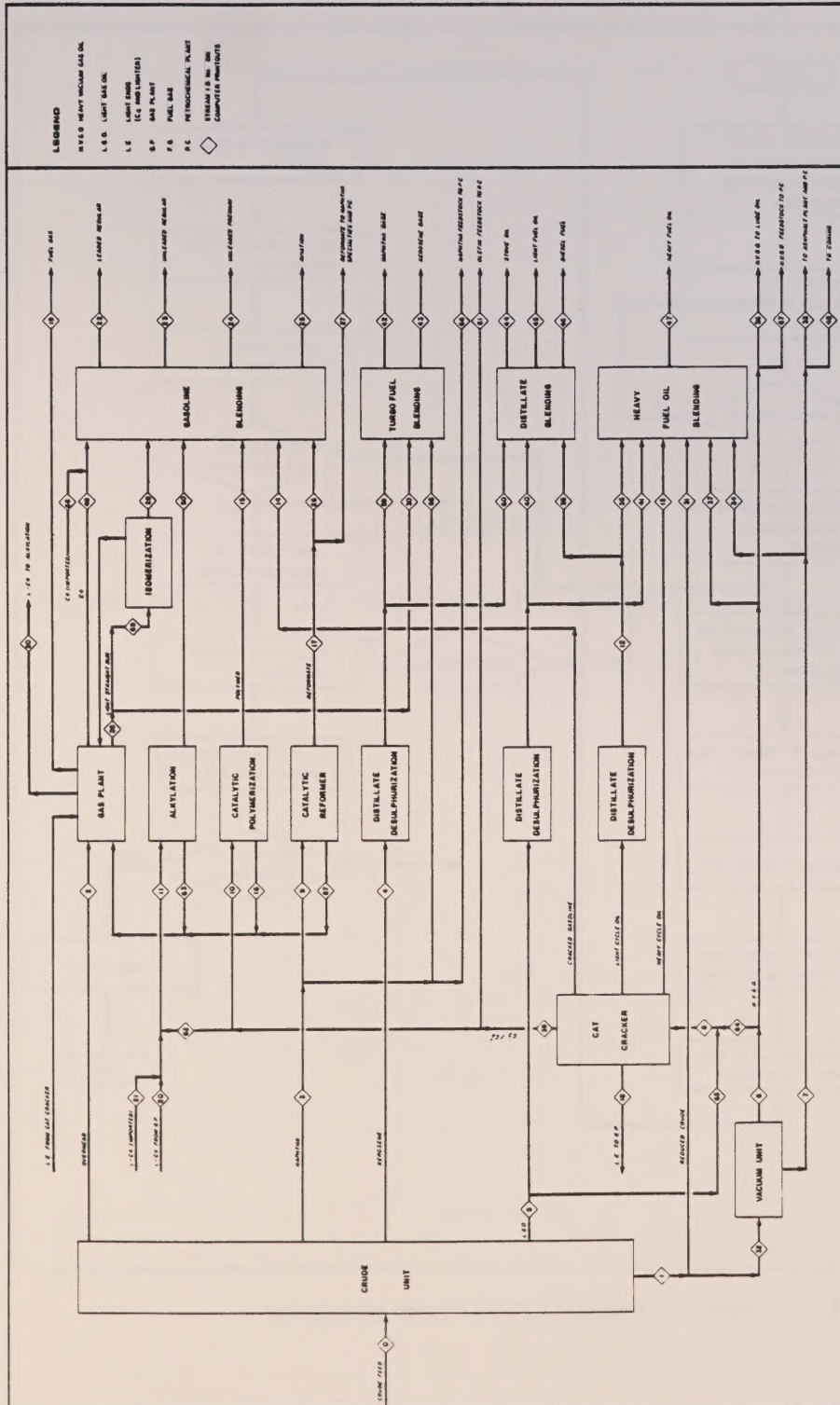


FIGURE 13 REFINERY MODEL OF BLOCK FLOW DIAGRAM

FIGURE 14 REFINERY SIMULATION FLOW DIAGRAM

APPENDIX II

SUMMARY OF COSTS, LEAD EMISSIONS, GASOLINE PRODUCTION AND DEMAND

TABLE 36 SUMMARY OF CONTROL OPTIONS FOR LEAD PHASE-DOWN IN GASOLINE

Option	1	2	3	4	5	6
Lead in Gasoline, g/gal	3.5	1.3	0.68	0	0+0.68 for Heavy Trucks	3.5 + Lead Trap for all new cars
<u>Period 1986-2000</u>						
Incremental Gasoline (billions gal)						
Lead-free Gasoline	-	-	-	37.4	26.2	-
Leaded Gasoline	37.4	37.4	37.4	0	11.2	37.4
Lead Emissions, tonnes	98 000	36 000	19 000	0	6 000	60 000
<u>Cost, \$ million</u>						
Refinery Investment	0	19	30	43	43	0
Refinery Operating Cost	0	210	336	485	485	0
Lead Traps	0	0	0	0	0	288
Total	0	229	366	528	528	288
Present Value, 1982	0	108	172	249	249	110
<u>Benefit, \$ million</u>						
Fuel Savings	0	0	0	775	775	0
Maintenance Savings	0	0	0	1 099	808	0
Total	0	0	0	1 874	1 583	0
Present Value, 1982	0	0	0	595	505	0
<u>Net Benefit (Cost), \$ million</u>						
Total	0	(229)	(366)	1 347	1 055	(288)
Present Value, 1982	0	(108)	(172)	346	256	(110)
<u>Cost Effectiveness, \$ per tonne</u>						
Net Benefit (Cost) of Lead Emitted (Present Value, 1982)	0	(1 740)	(2 180)	3 530	2 780	(2 890)
<u>Cents Per Gallon of Incremental Gasoline*</u>						
Cost	-	0.6	0.9	1.4	1.4	0.8
Benefit	-	-	-	5.1	4.3	-
Net Benefit or (Cost)	-	(0.6)	(0.9)	3.7	2.9	(0.8)
<u>Cents Per Litre of Incremental Gasoline*</u>						
Cost	-	0.13	0.20	0.31	0.31	0.18
Benefit	-	-	-	1.12	0.95	-
Net Benefit or (Cost)	-	(0.13)	(0.20)	0.81	0.64	(0.18)

* Incremental Gasoline - means the volume of leaded gasoline that would be used from 1982 to 2000. This incremental volume does not include lead-free gasoline, predicted to be used for the status quo option 1.

TABLE 37 VEHICLE POPULATION AND FLEET RATING

Year	Vehicle Population (million)			Fleet Rating (miles per gallon)		
	Passenger Cars	Light Duty	Medium/Heavy	Passenger Cars	Light Duty	Medium/Heavy
1978	9.8	2.1	0.37	16.6	12.4	6.5
1979	10.3	2.4	0.37	17.2	12.4	6.5
1980	10.5	2.6	0.37	17.9	12.4	6.5
1981	10.7	2.8	0.37	18.8	12.7	6.6
1982	10.8	3.0	0.37	19.9	13.3	6.7
1983	11.0	3.2	0.37	21.1	14.0	6.7
1984	11.2	3.4	0.38	22.3	14.8	6.9
1985	11.4	3.5	0.39	23.7	15.6	7.0
1986	11.5	3.6	0.40	25.1	16.5	7.1
1987	11.7	3.7	0.41	26.4	17.5	7.2
1988	11.8	3.9	0.42	27.7	18.4	7.3
1989	11.9	3.9	0.42	28.9	19.3	7.4
1990	12.1	4.1	0.43	30.1	20.2	7.5

TABLE 38 ESTIMATED GASOLINE PRODUCTION AND DEMAND, 1986 TO 2000

Year	Production (10 ⁹ gallons)		Demand, Leaded Gasoline (10 ⁹ gallons)		
	Lead-Free	Leaded	Passenger Cars	Light Duty	Heavy
1986	5.00	3.03	1.30	1.03	0.70
1987	5.10	2.85	1.10	1.05	0.70
1988	5.10	2.76	1.00	1.06	0.70
1989	5.20	2.57	0.90	0.97	0.70
1990	5.20	2.49	0.80	0.89	0.80
1991	5.15	2.46	0.79	0.88	0.79
1992	5.09	2.44	0.78	0.88	0.78
1993	5.04	2.41	0.77	0.86	0.78
1994	4.99	2.39	0.77	0.85	0.77
1995	4.94	2.36	0.76	0.84	0.76
1996	4.91	2.35	0.76	0.83	0.76
1997	4.88	2.33	0.75	0.83	0.75
1998	4.85	2.32	0.75	0.82	0.75
1999	4.82	2.30	0.74	0.82	0.74
2000	4.79	2.29	0.74	0.81	0.74
TOTAL	75.06	37.35	12.71	13.42	11.22

TABLE 39 ESTIMATED AUTOMOTIVE LEAD EMISSIONS, 1986 TO 2000 (TONNES PER YEAR)

Option	1	2	3	4	5	6
<u>Year</u>						
1986	8 000	3 000	1 500	0	400	8 000
1987	7 500	2 800	1 500	0	400	7 000
1988	7 200	2 700	1 400	0	400	6 300
1989	6 700	2 500	1 300	0	400	5 400
1990	6 500	2 400	1 300	0	400	4 700
1991	6 500	2 400	1 300	0	400	4 400
1992	6 400	2 400	1 200	0	400	3 900
1993	6 300	2 400	1 200	0	400	3 500
1994	6 300	2 300	1 200	0	400	3 100
1995	6 200	2 300	1 200	0	400	2 800
1996	6 200	2 300	1 200	0	400	2 500
1997	6 100	2 300	1 200	0	400	2 300
1998	6 100	2 300	1 200	0	400	2 100
1999	6 000	2 200	1 200	0	400	2 000
2000	6 000	2 200	1 200		400	2 000
TOTAL	98 000	36 400	19 000	0	5 700	60 000

TABLE 40 ESTIMATED COSTS FOR CONTROL OPTIONS

Refinery Capital Cost (\$ million, 1982)				
Option	2	3	4	5
1983	3.7	6.0	8.6	8.6
1984	6.5	10.6	15.1	15.1
1985	8.8	13.4	19.3	19.3
TOTAL	19.0	30.0	43.0	43.0

Refinery Operating Cost (\$ million, 1982)				
Option	2	3	4	5
1986	14.0	22.5	32.3	32.3
	↓	↓	↓	↓
2000	14.0	22.5	32.3	32.3
TOTAL	210	338	485	485

Option 6Differential Costs of Lead Trap - Standard Muffler
(\$ million, 1982)

	Passenger Cars	Light Duty/Medium	Heavy	Total
1986	6.8	8.4	4.0	19.2
	↓	↓	↓	↓
2000	6.8	8.4	4.0	19.2
TOTAL	102	126	60	288

TABLE 41 INCREMENTAL SAVINGS FOR LEAD-FREE GASOLINE OPTION
(\$ million, 1982)

Year	Maintenance ^a	Fuel Usage ^b	Total
1986	13.0	10.5	23.5
1987	28.2	18.0	46.2
1988	36.1	24.8	60.9
1989	44.8	30.6	75.4
1990	54.3	34.7	89.0
1991	63.9	41.3	105.2
1992	74.8	49.3	124.1
1993	83.9	56.6	140.5
1994	93.4	64.0	157.4
1995	102.6	71.8	174.4
1996	102.1	73.1	175.2
1997	101.3	73.6	174.9
1998	100.8	74.9	175.7
1999	100.0	75.1	175.1
2000	99.5	76.5	176.0
TOTAL	1 098.7	774.8	1 873.5

a For all vehicles converting from leaded to lead-free gasoline.

b For passenger cars converting from leaded to lead-free gasoline.

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Control options for
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